本节内容

归并排序
(Merge Sort)

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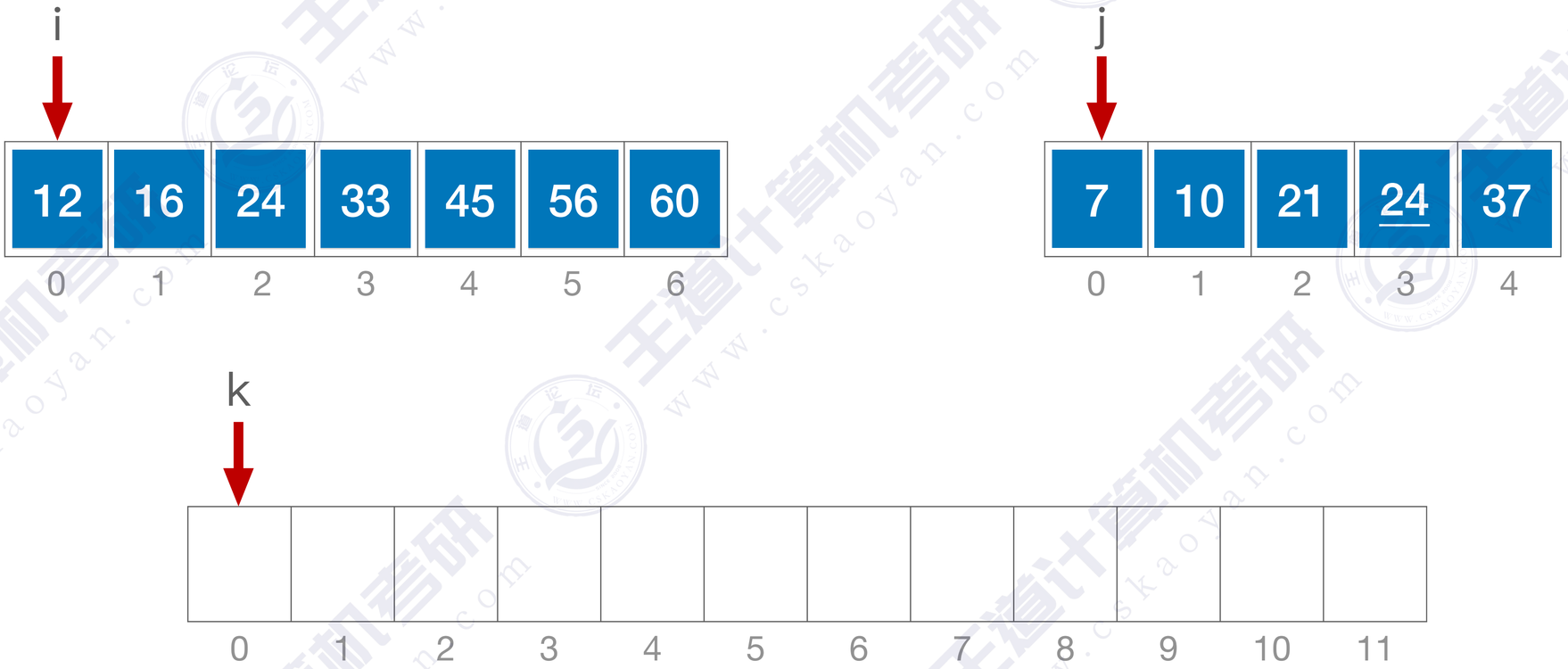
什么是 Merge（归并/合并）？

归并：把两个或多个已经有序的序列合并成一个



对比 i、j 所指元素，选择更小的一个放入 k 所指位置

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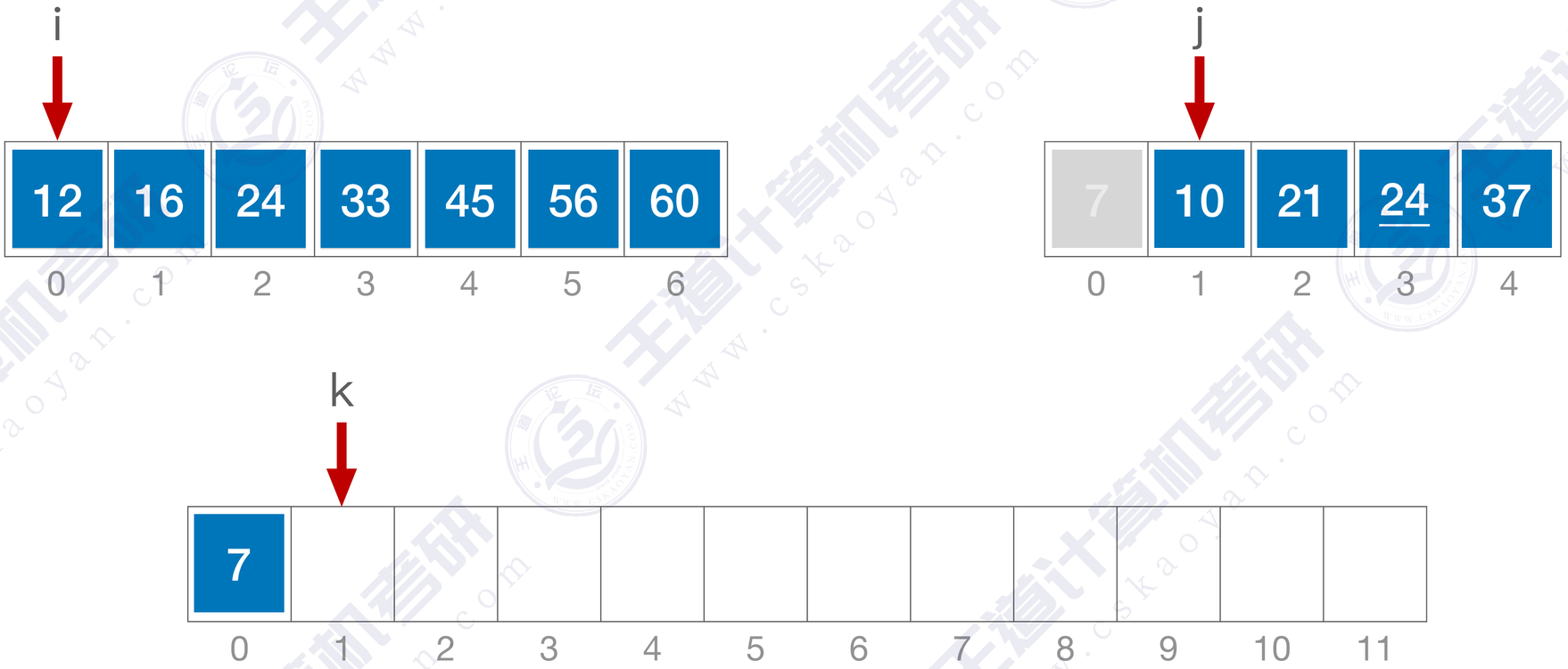

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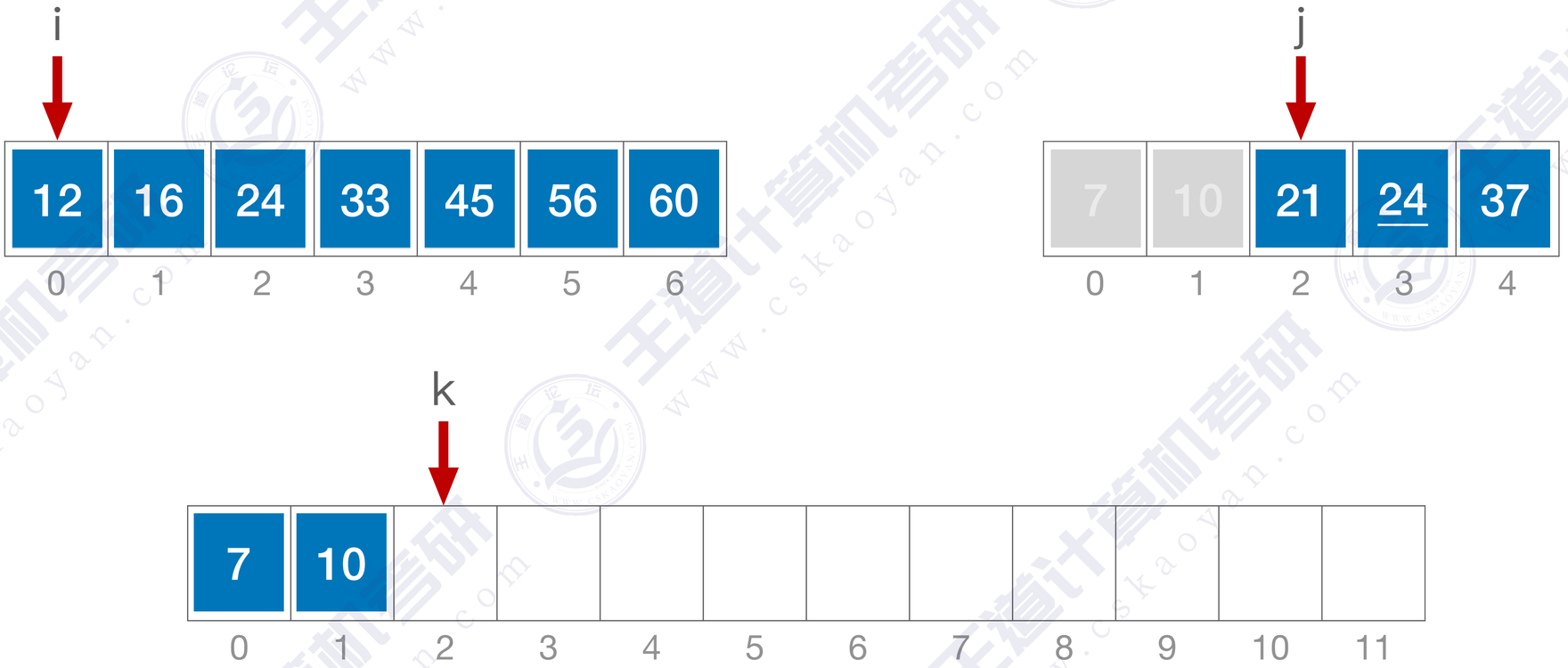

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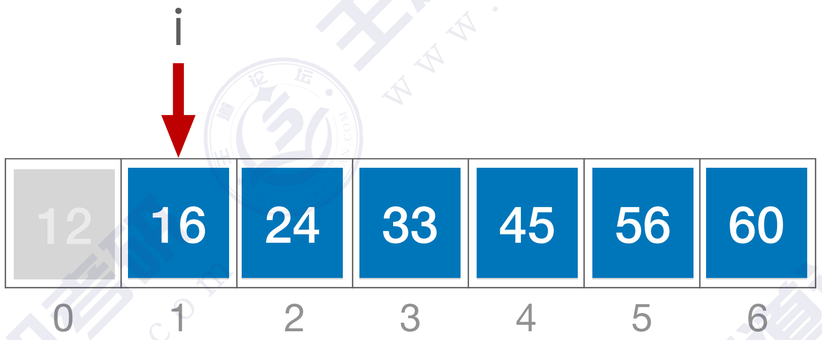

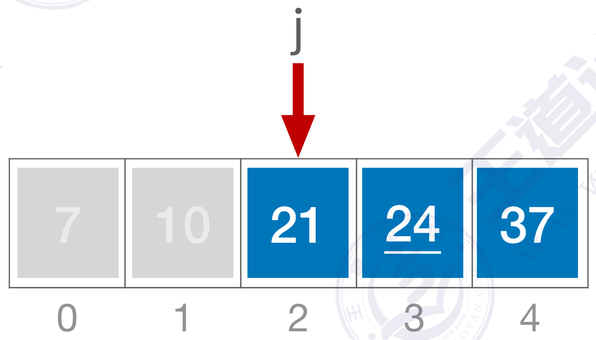

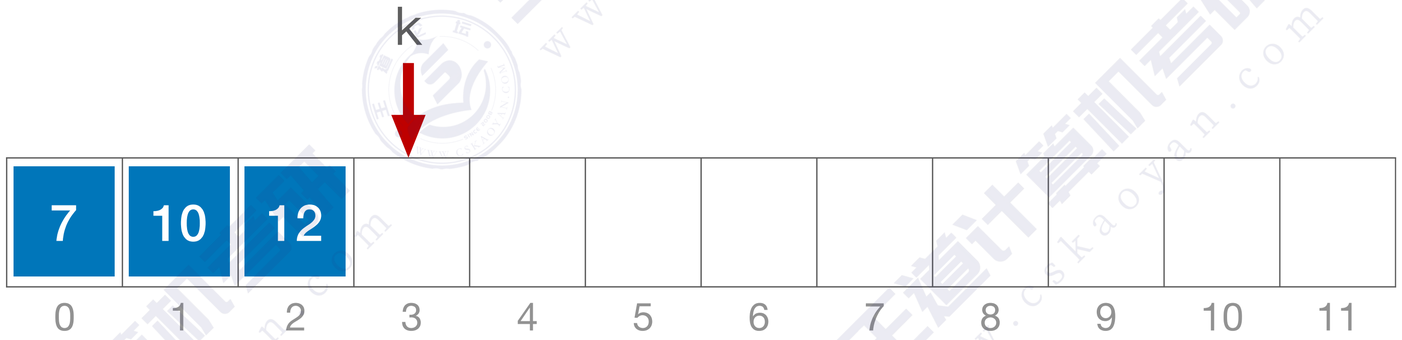

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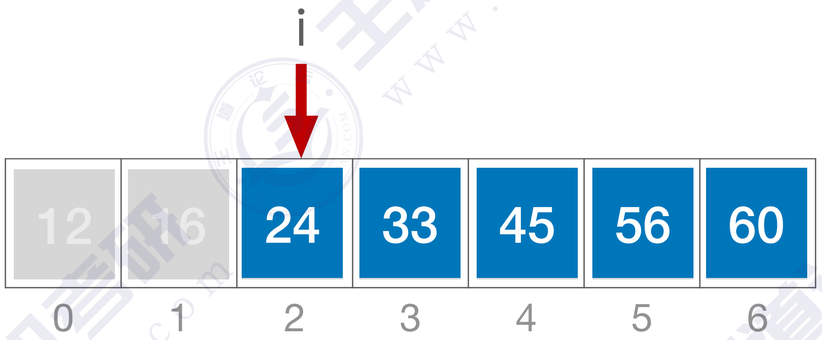

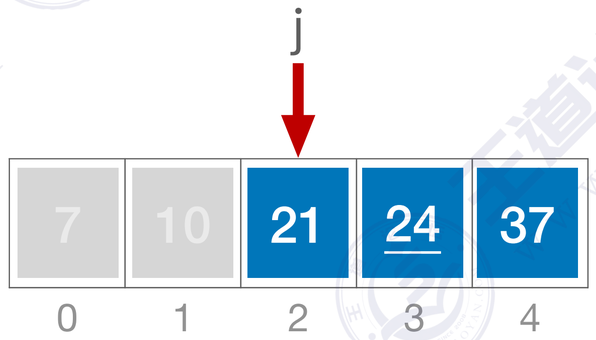

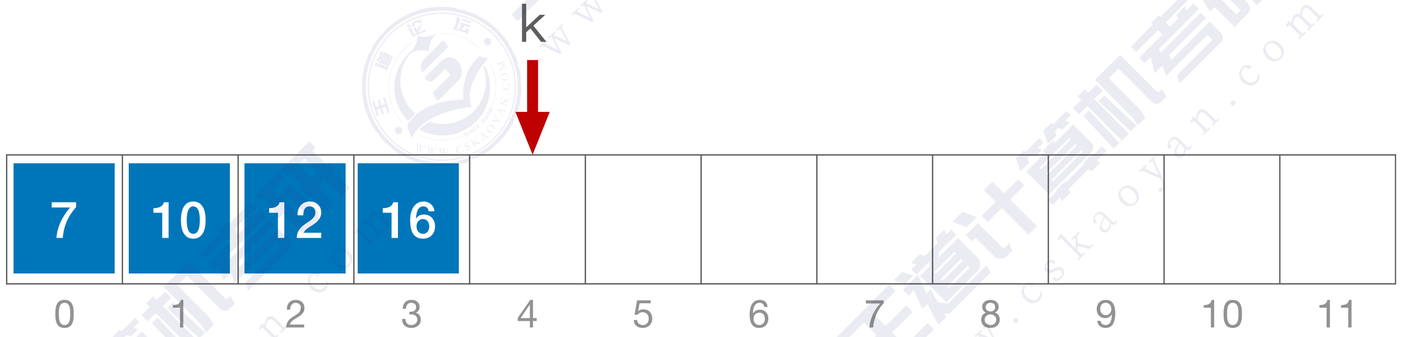

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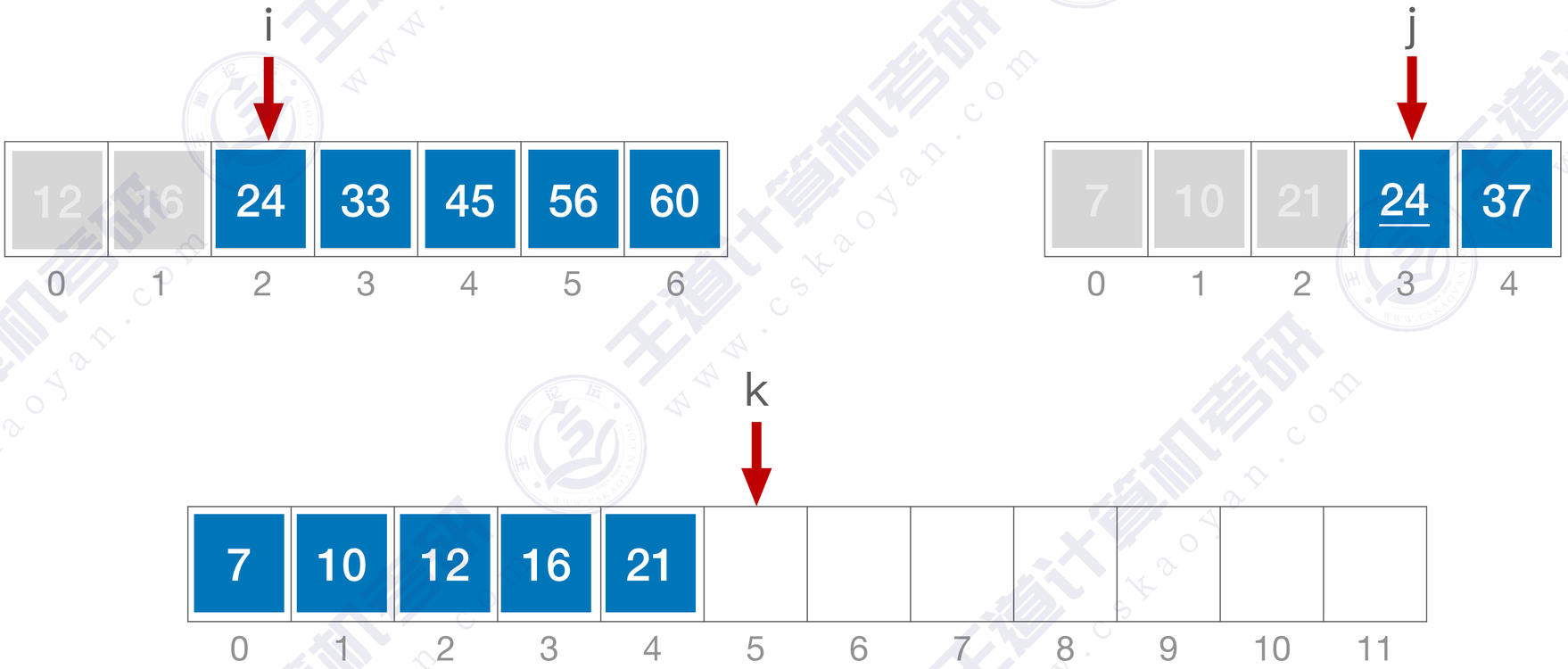

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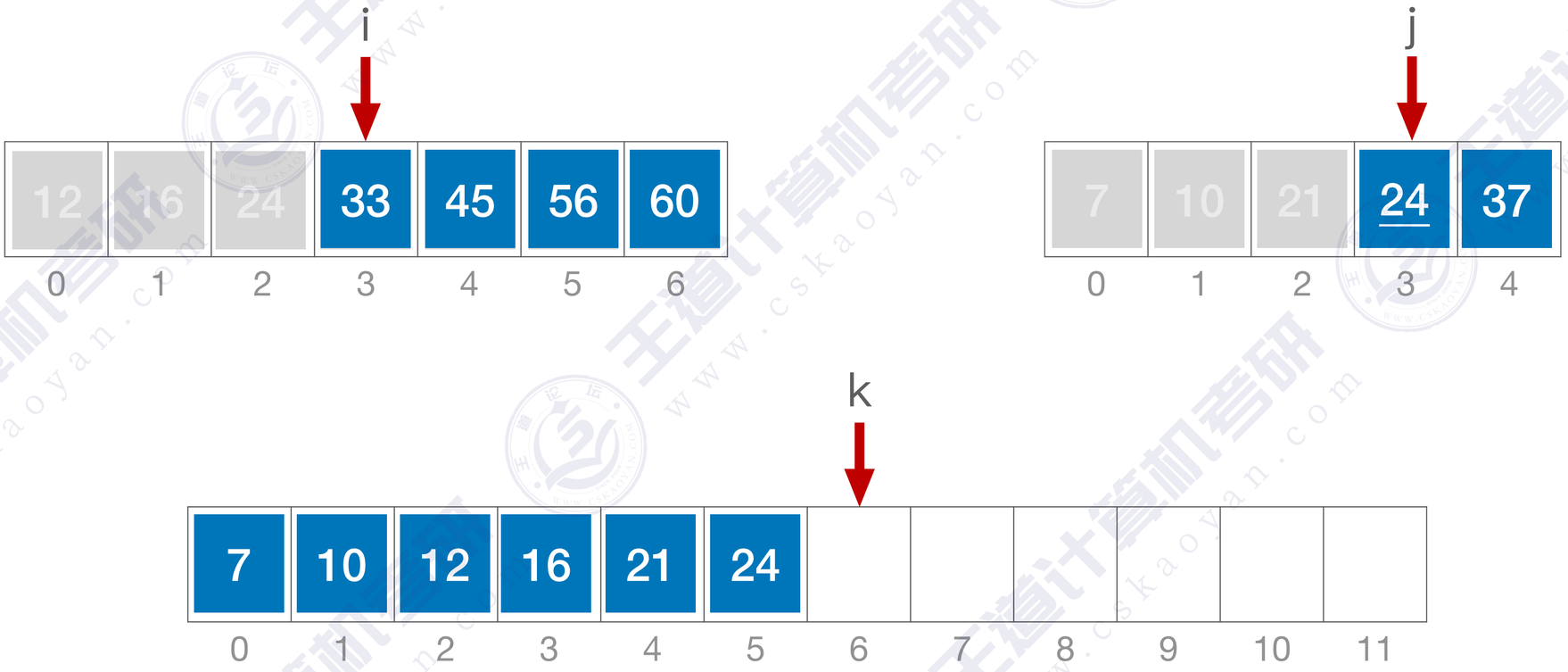

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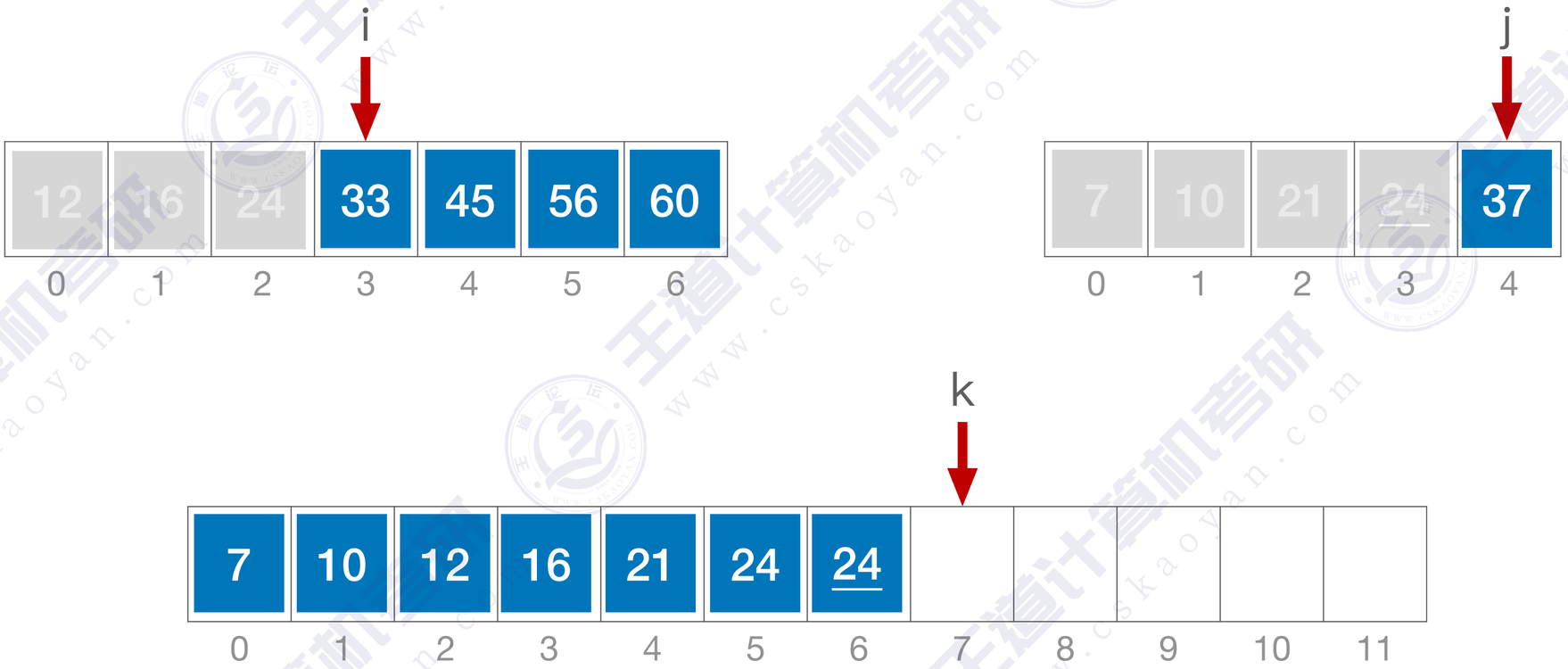

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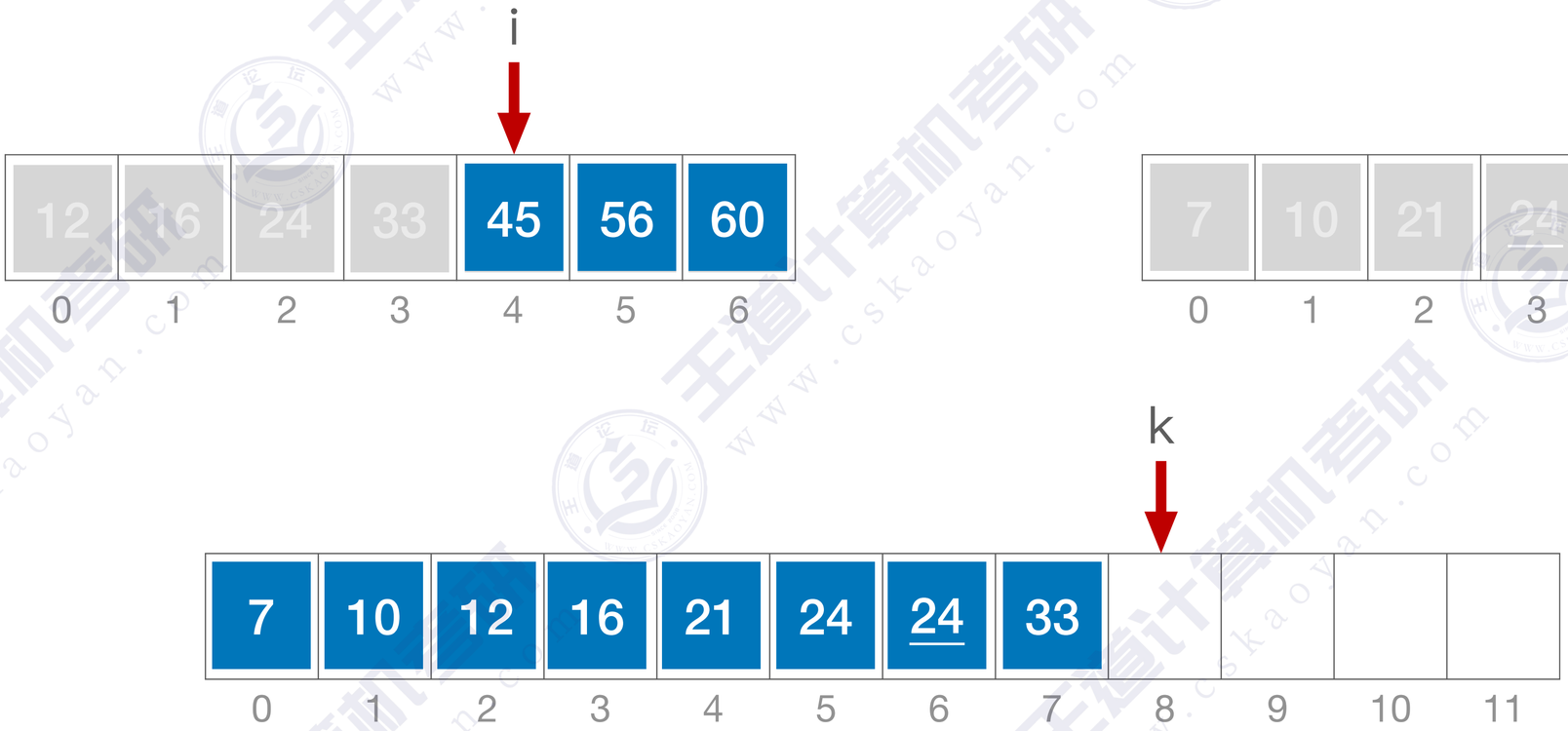

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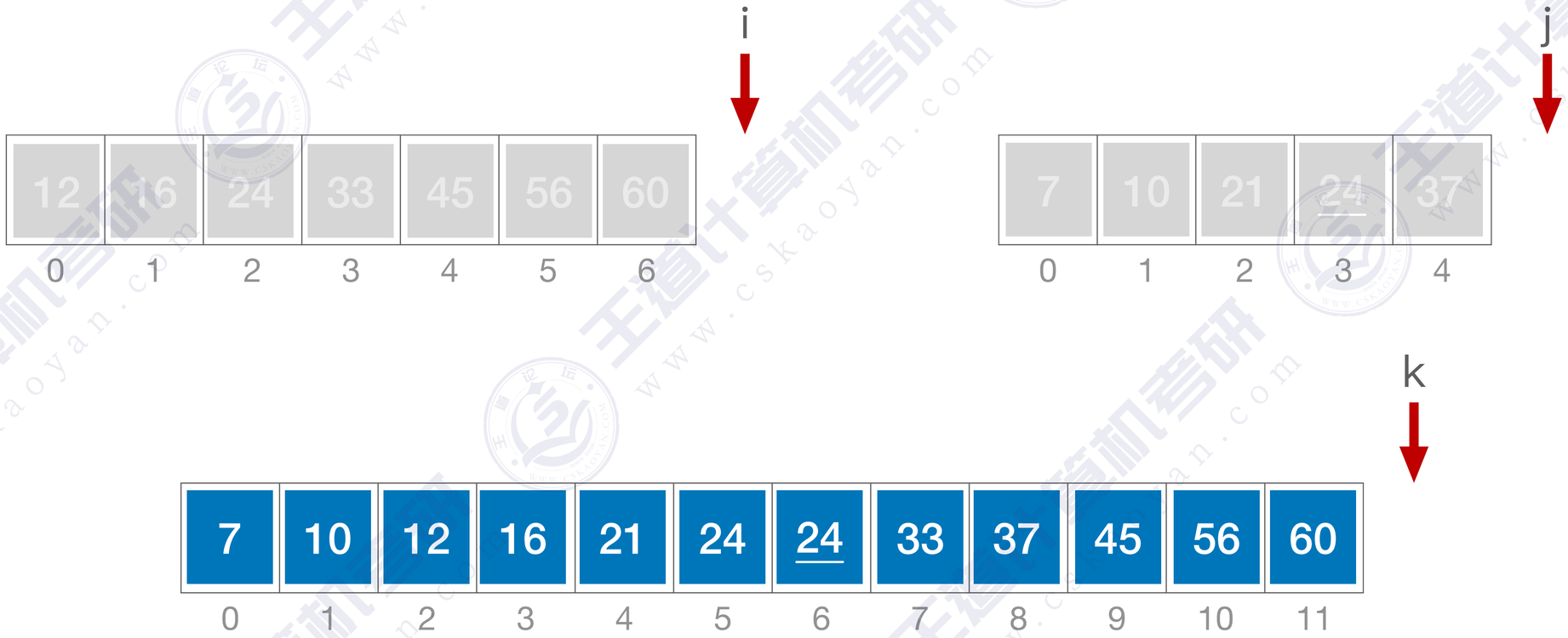

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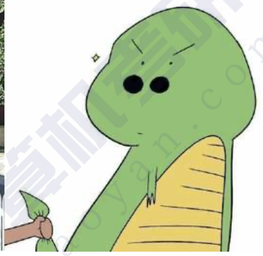
“2路”归并

“2路”——二合一



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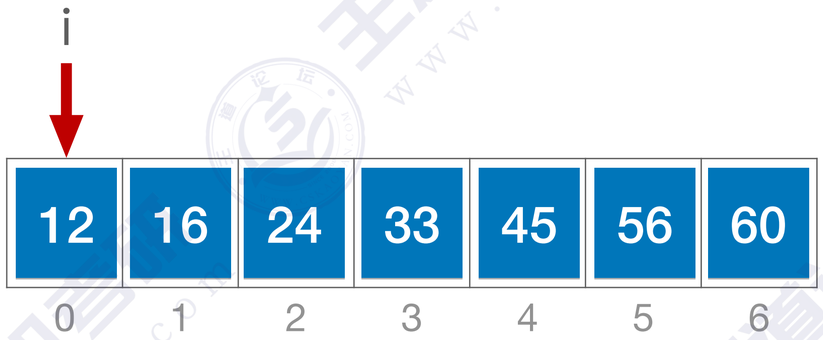

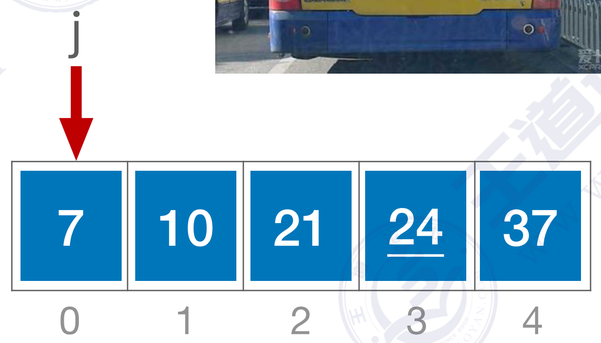

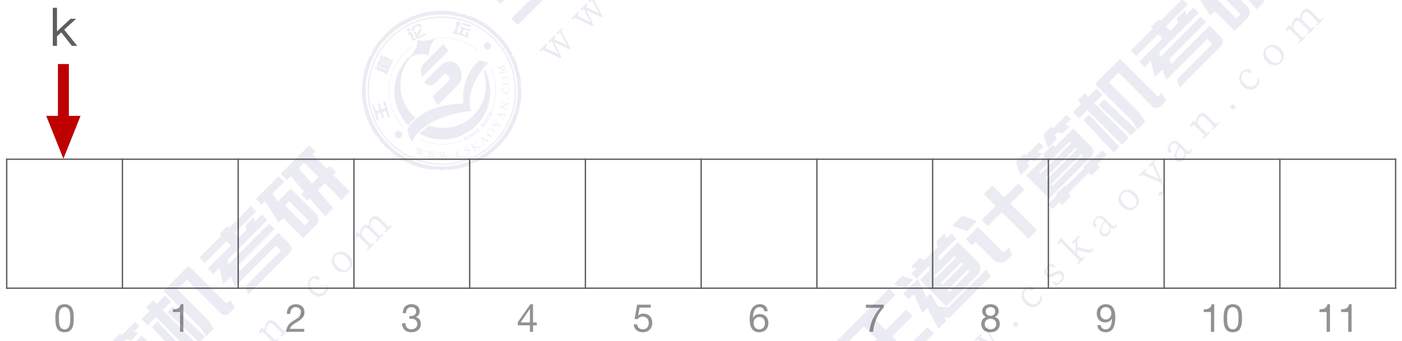

“2路”归并——每选出一个小元素注需对比关键字1次

对比 i、j 所指元素，选择更小的一个放入 k 所指位置

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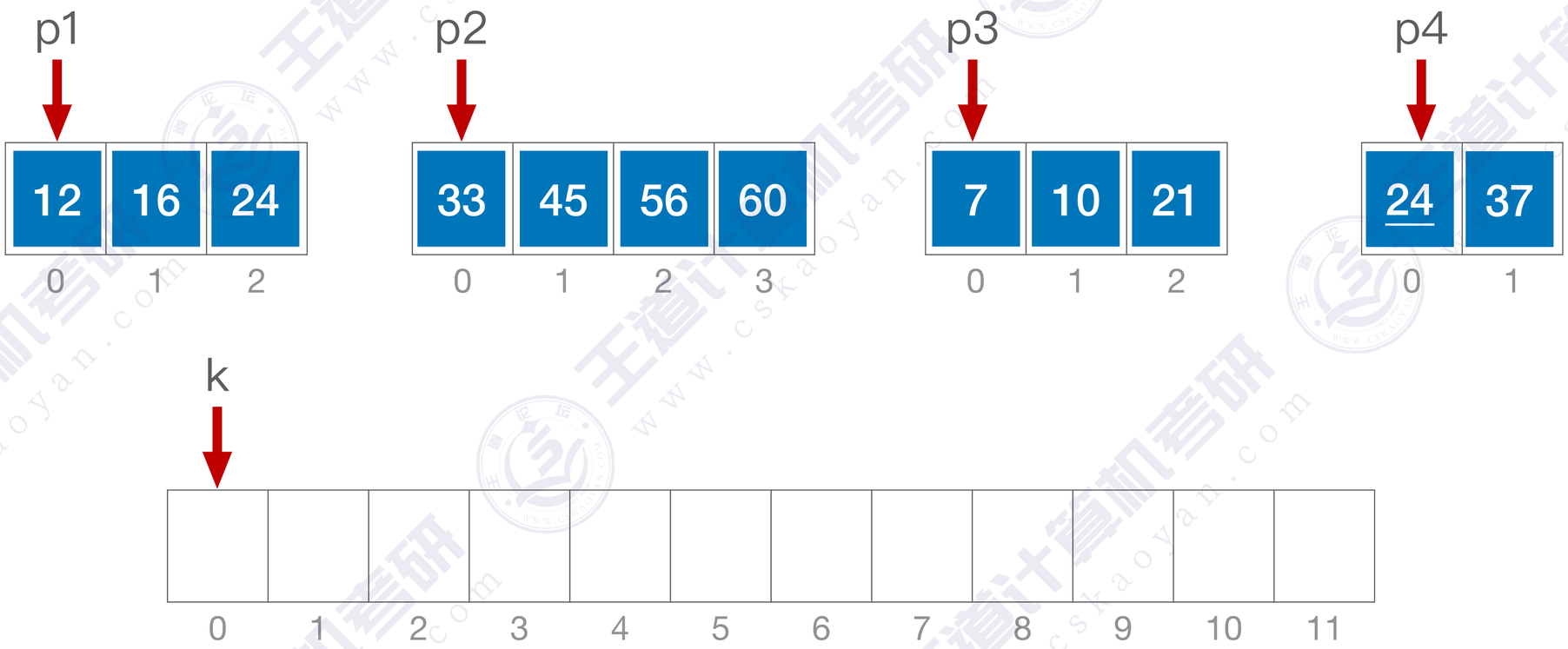
“4路”——四合一 “4路”归并

归并：把两个或多个已经有序的序列合并成一个



“4路”归并——每选出一个小元素注需对比关键字3次

对比 p1、p2、p3、p4所指元素，选择更小的一个放入 k 所指位置

结论：m路归并，每选出一个元素需要对比关键字 m-1 次

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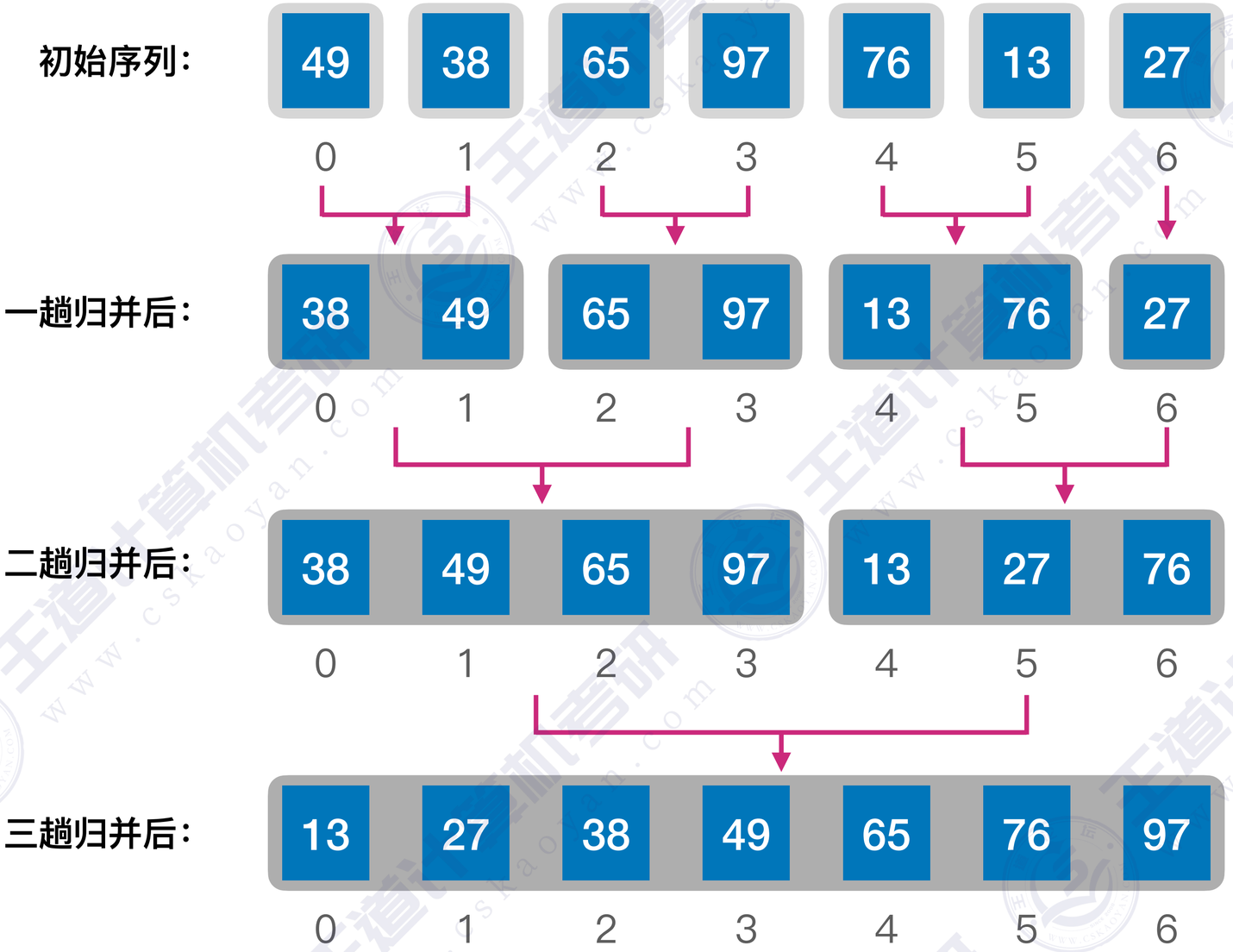
在内部排序中一般采用2路归并

归并排序（手算模拟）



核心操作：把数组内的两个有序序列归并为一个

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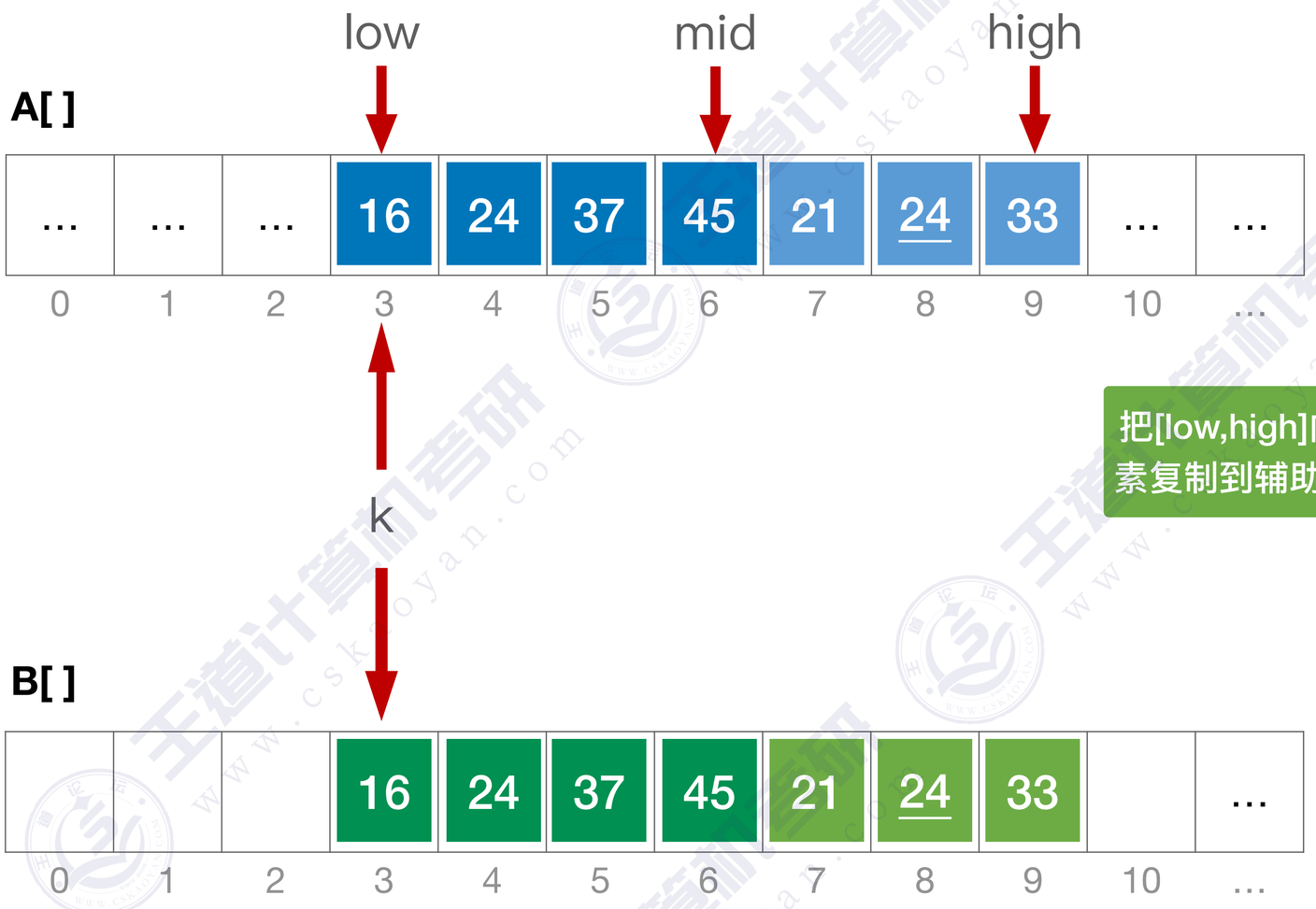
代码实现



把[low,high]内的元素复制到辅助数组B

```
int *B=(int *)malloc(n*sizeof(int)); //辅助数组B


//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];                  //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
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```

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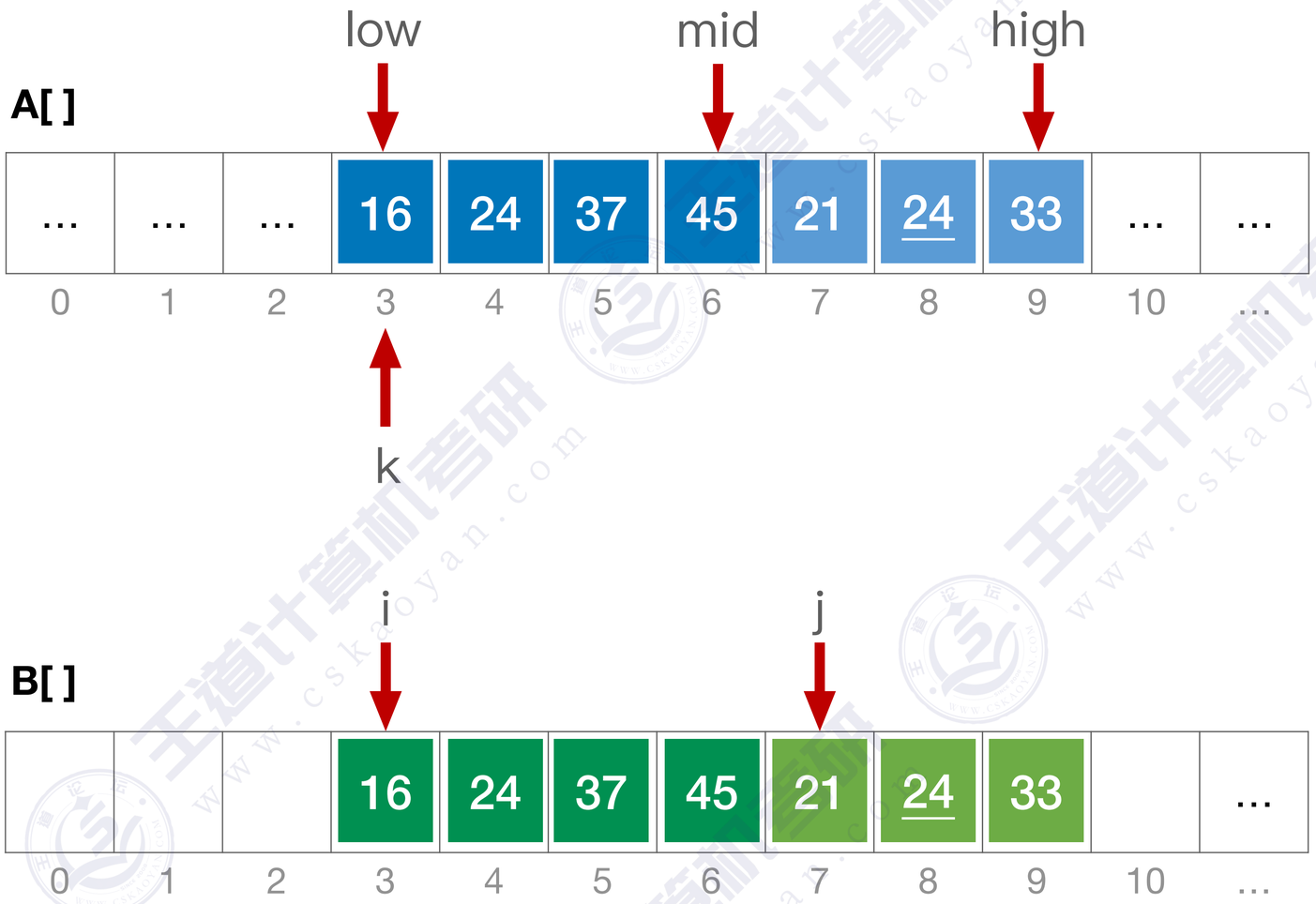


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    while(i<=mid)   A[k++]=B[i++];
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}
```

归并

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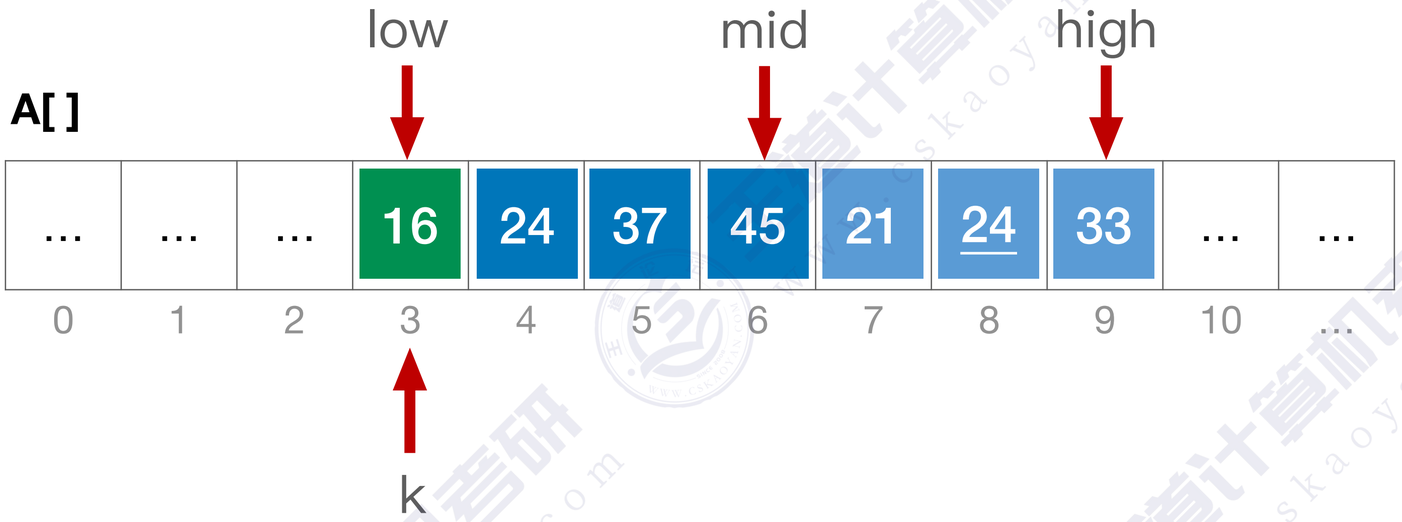


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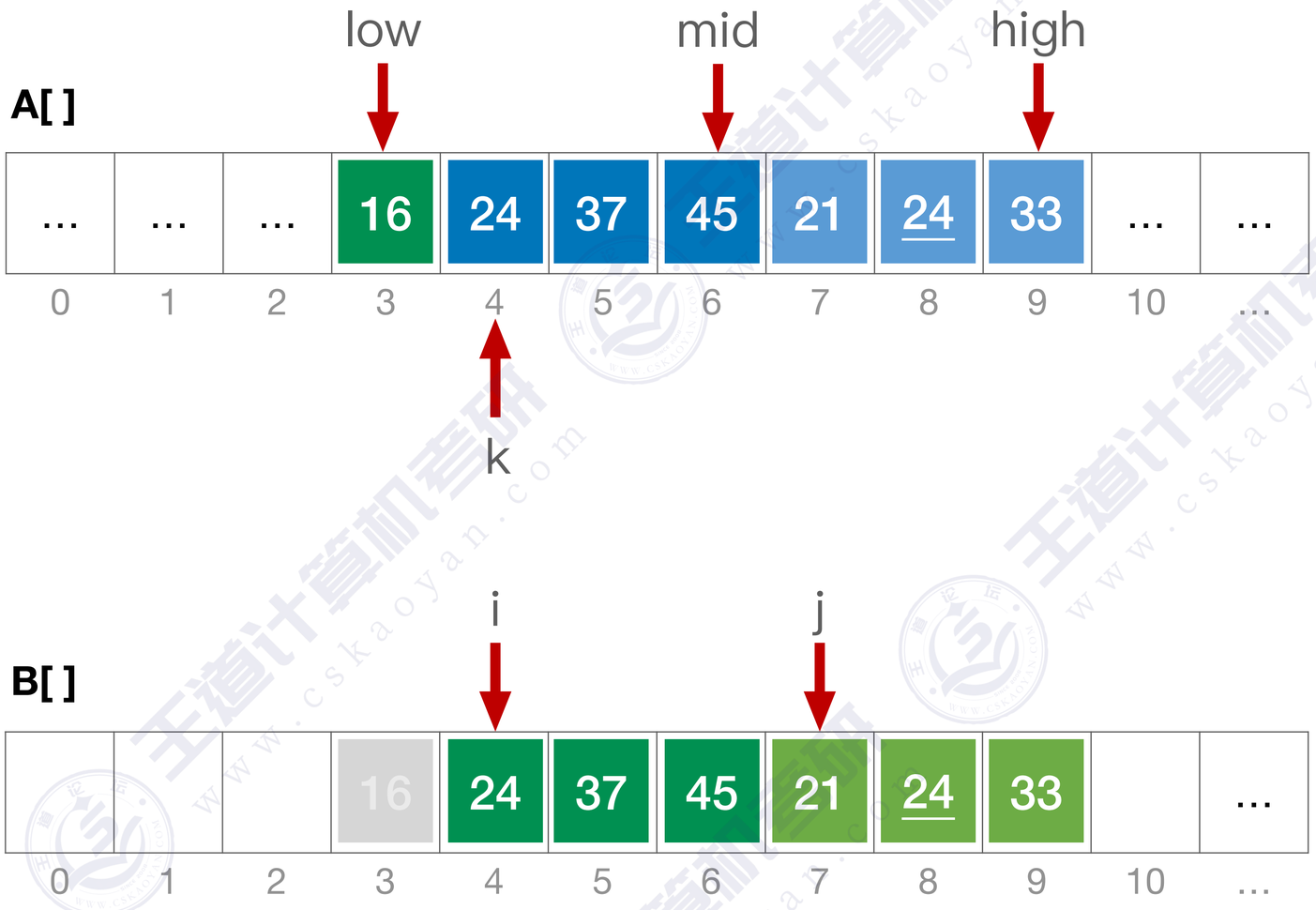


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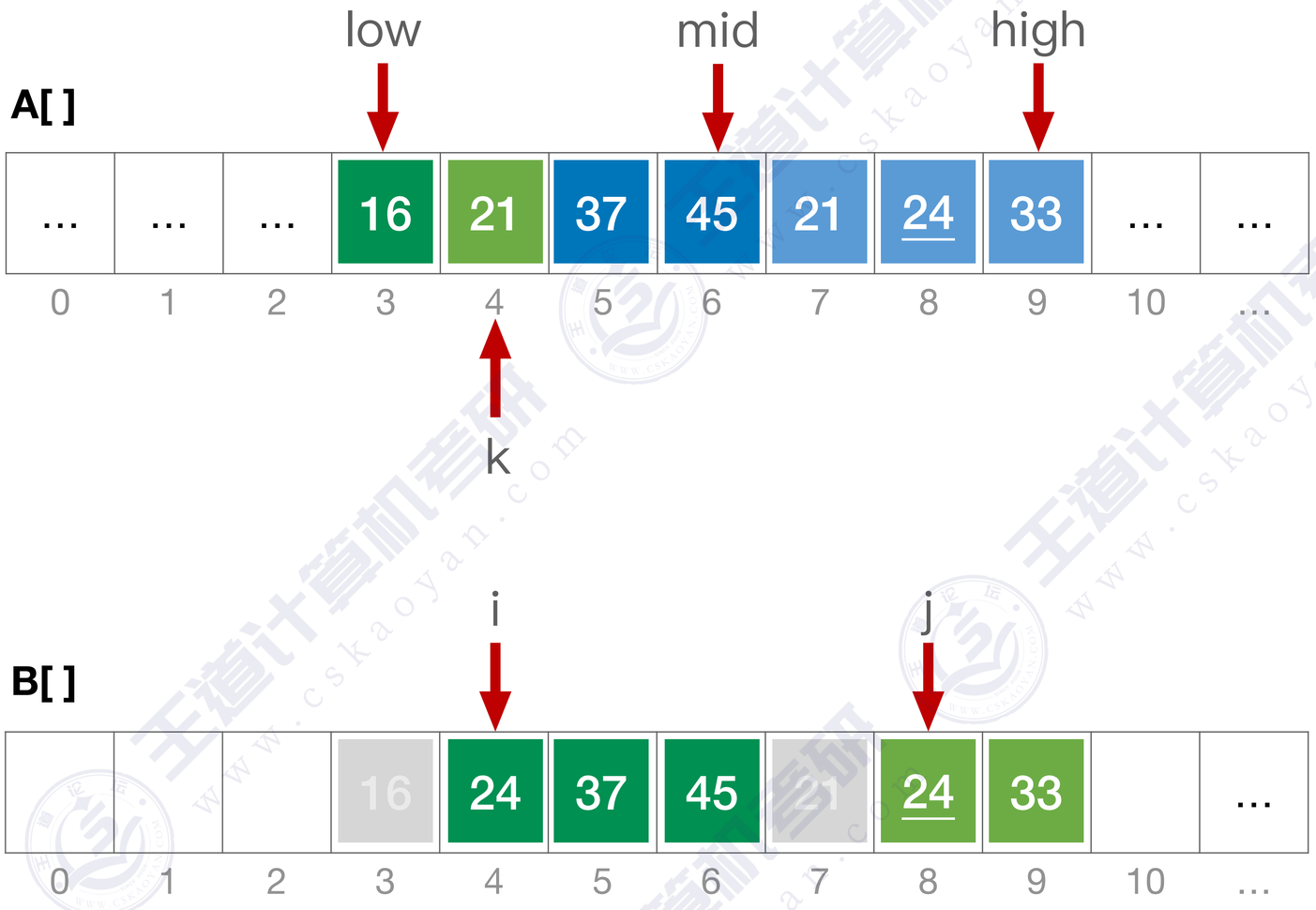


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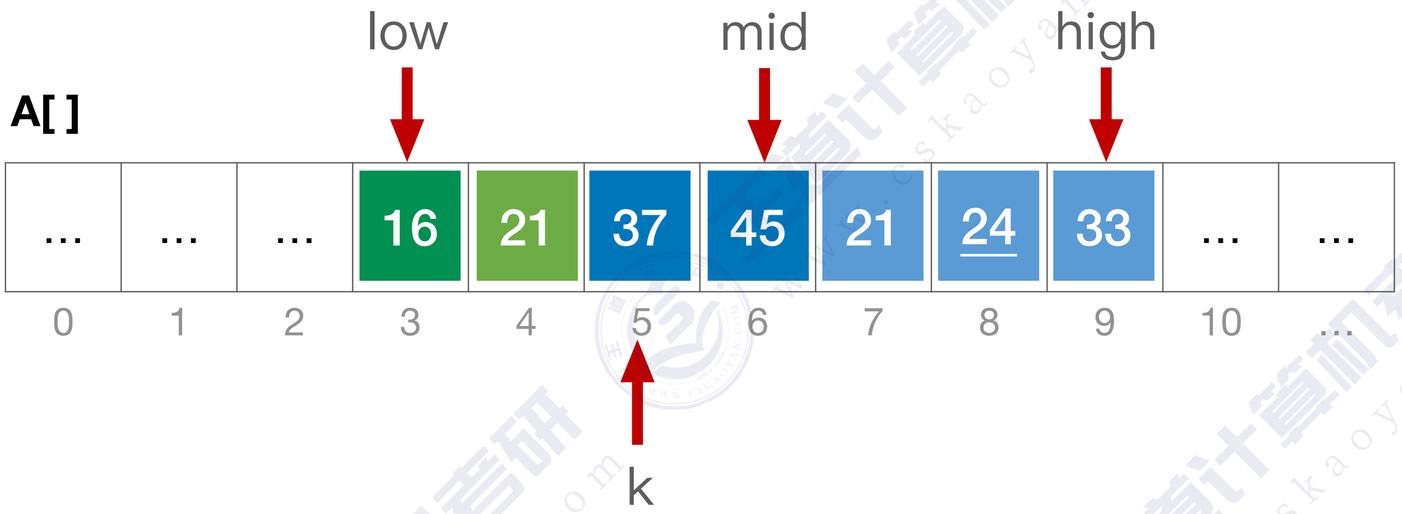

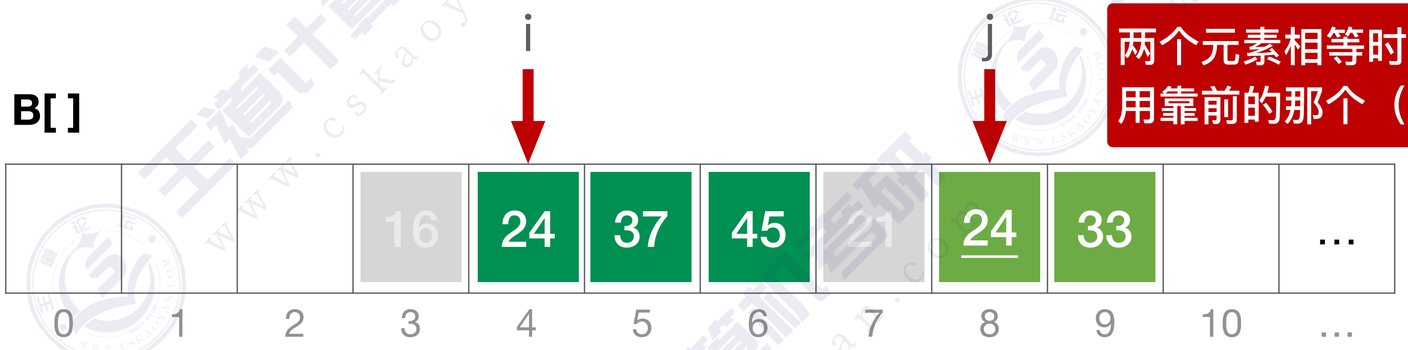

两个元素相等时，优先使用靠前的那个（稳定性）

归并

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        else
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    }//for
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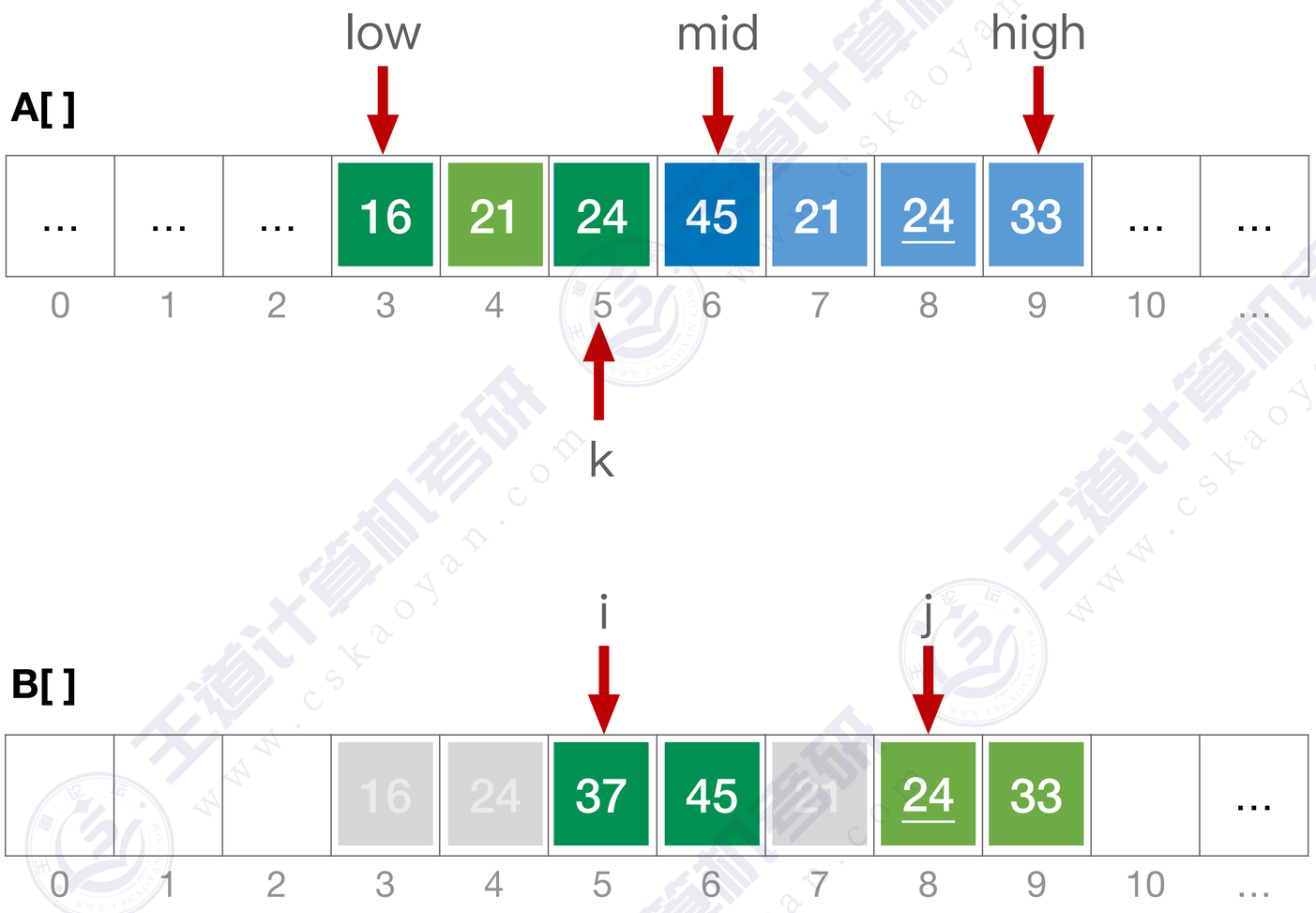


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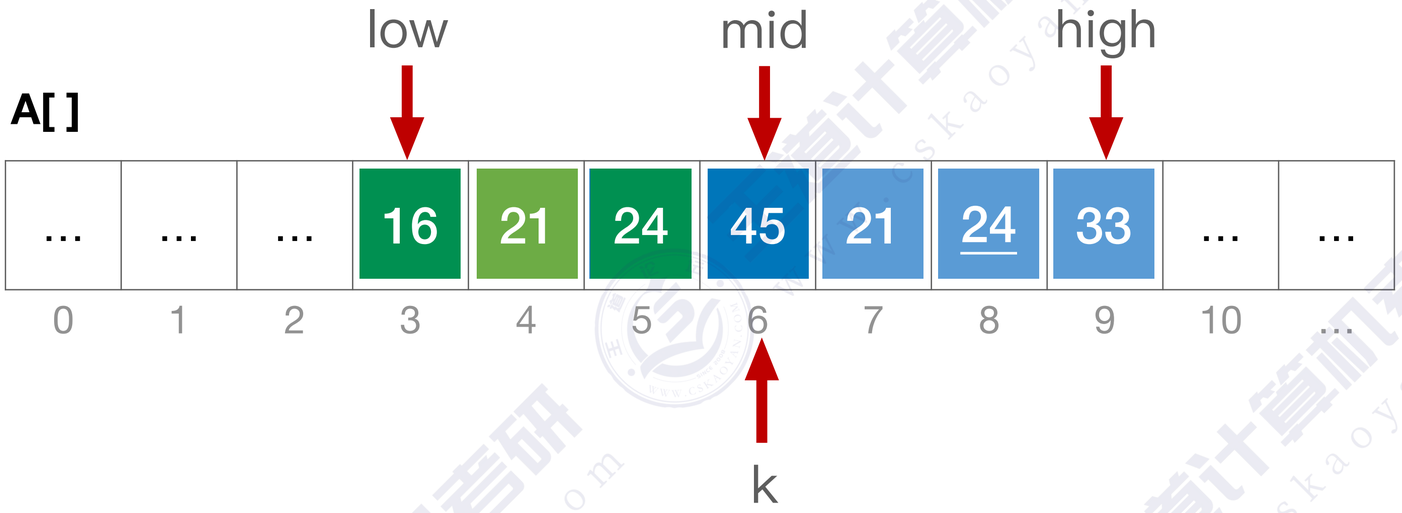

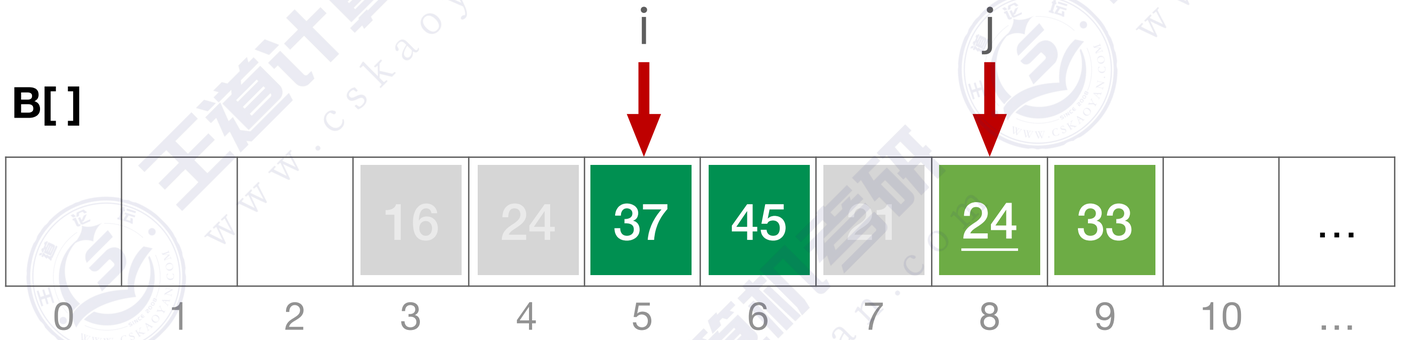


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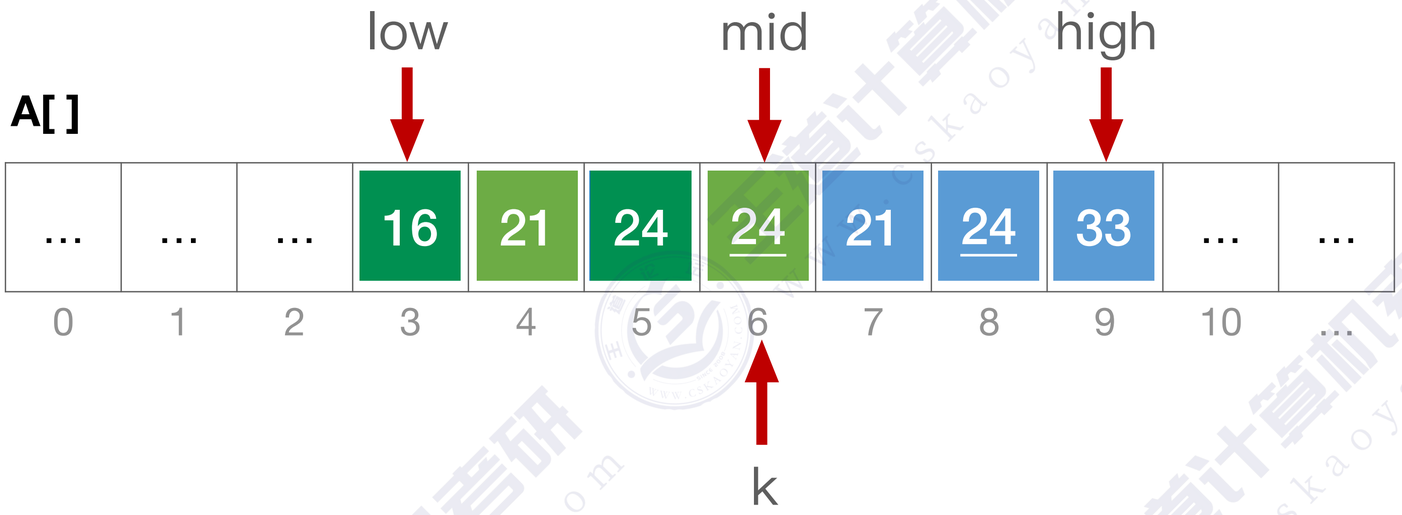

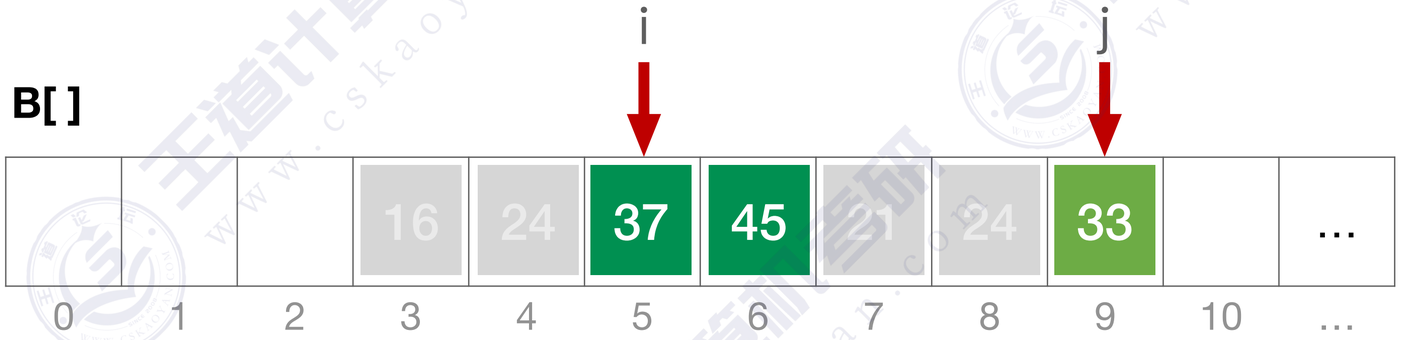


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//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];              //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

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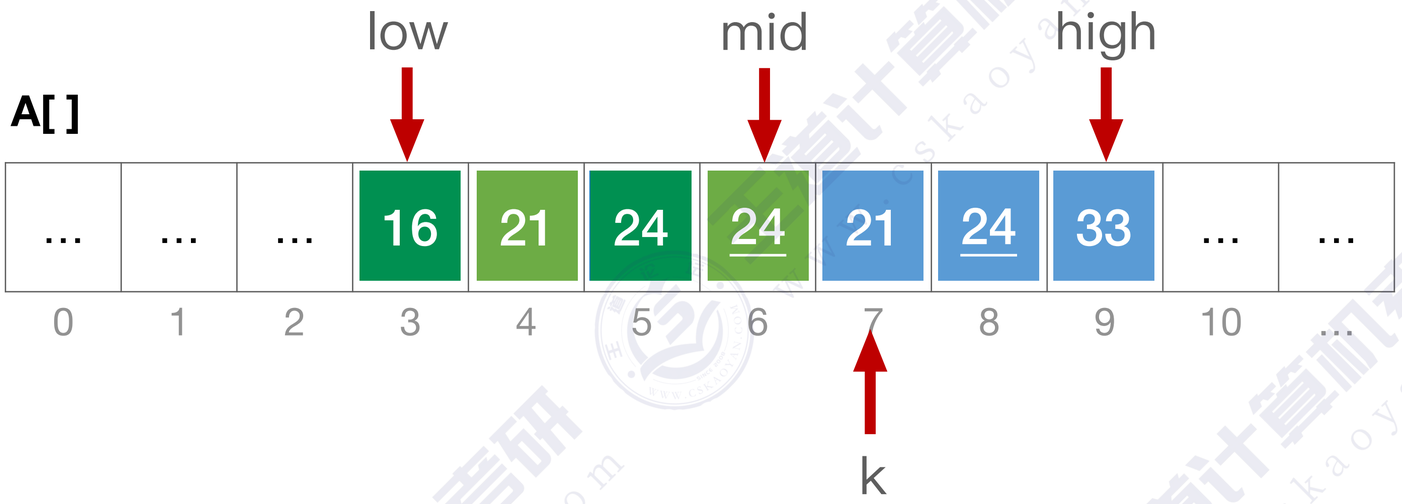
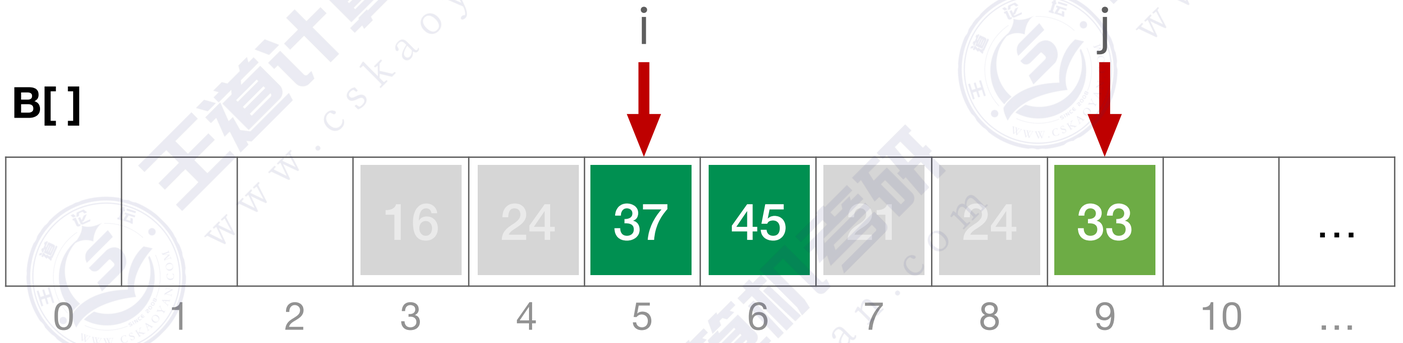
代码实现






```
int *B=(int *)malloc(n*sizeof(int)); //辅助数组B


//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];                  //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

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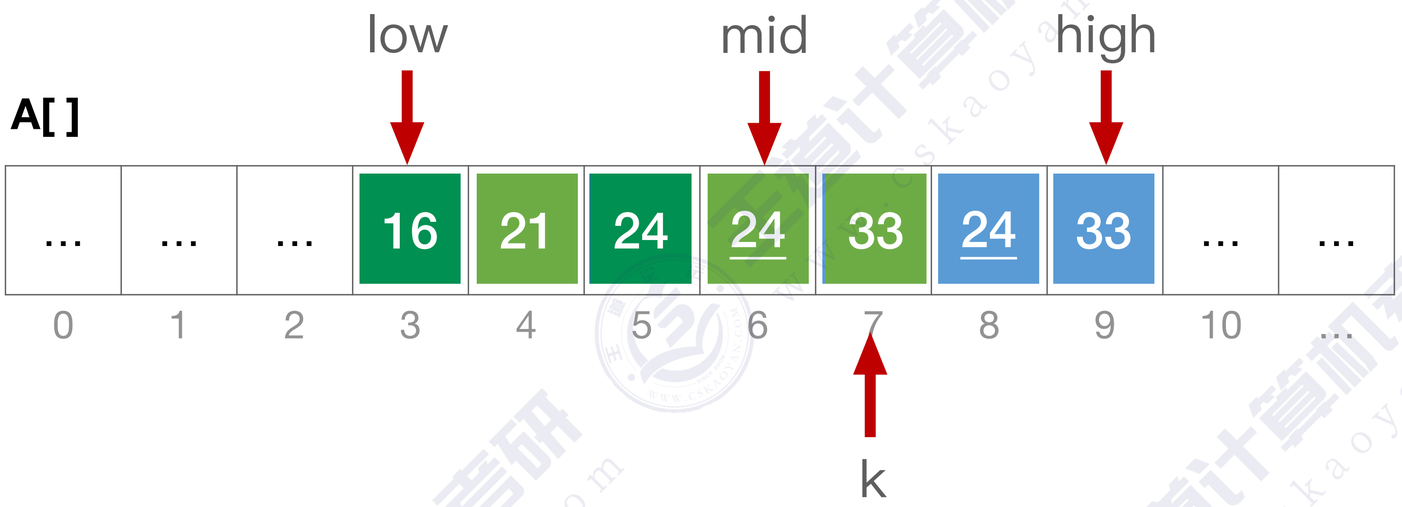
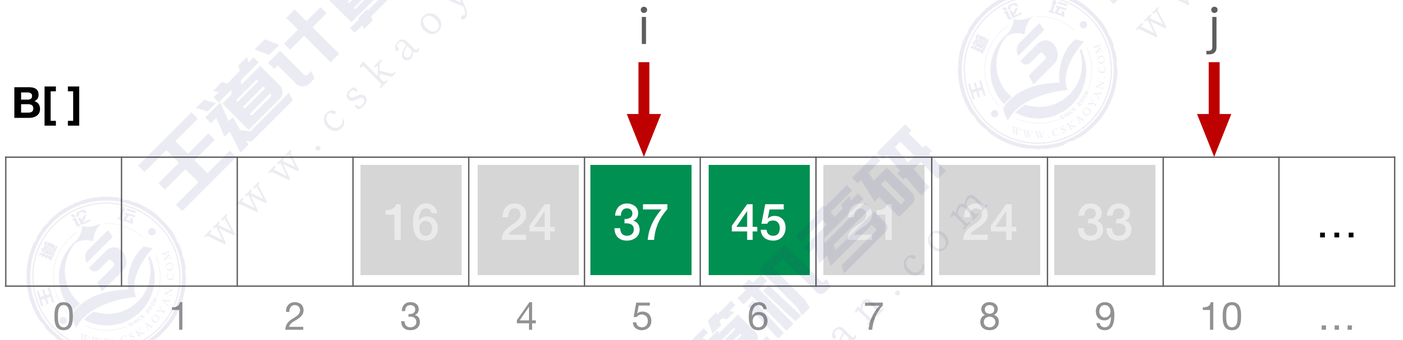
代码实现






```
int *B=(int *)malloc(n*sizeof(int)); //辅助数组B


//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
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        B[k]=A[k];              //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

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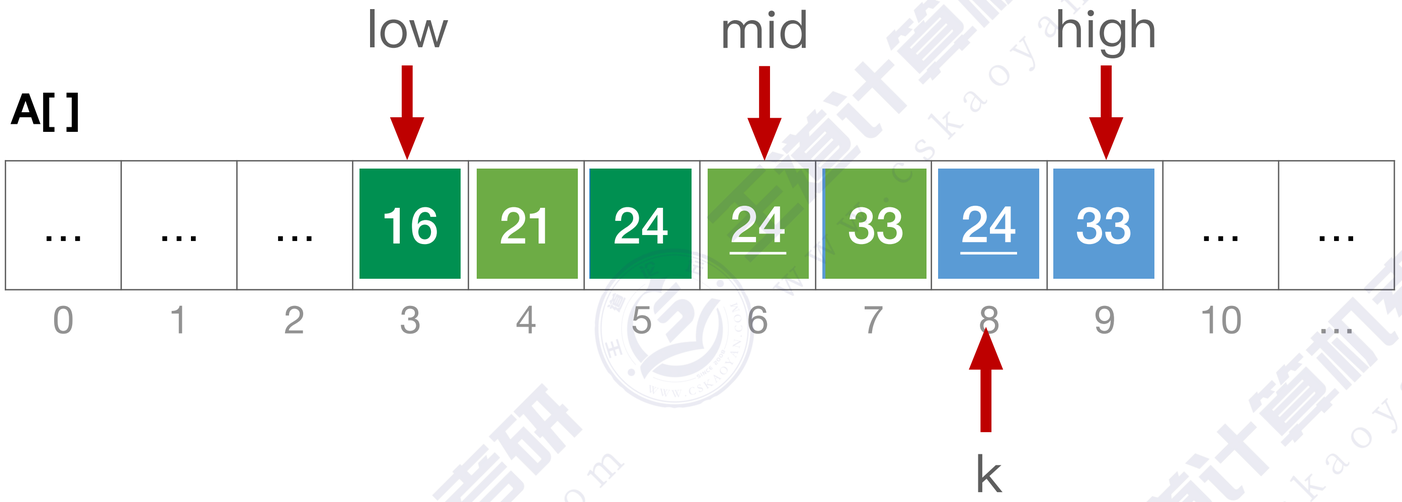
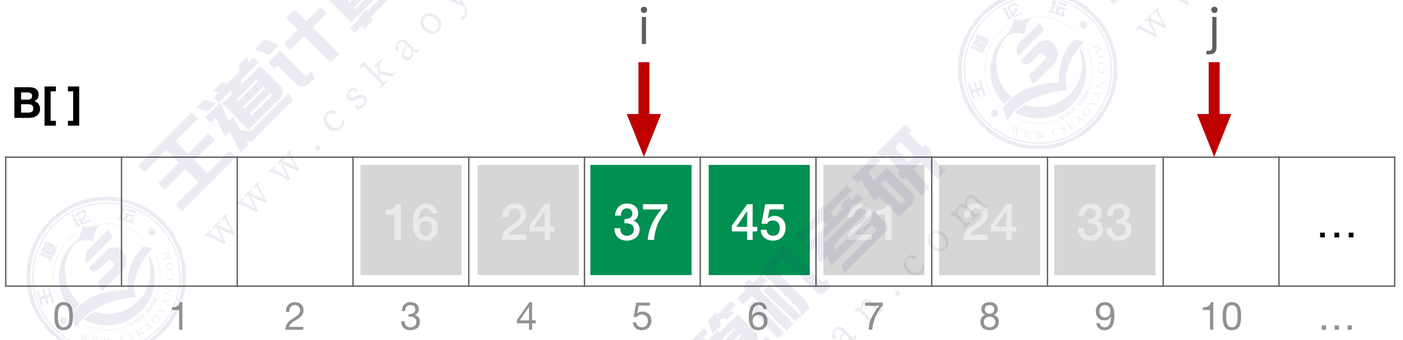
代码实现



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    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

没有归并完的部分复制到尾部

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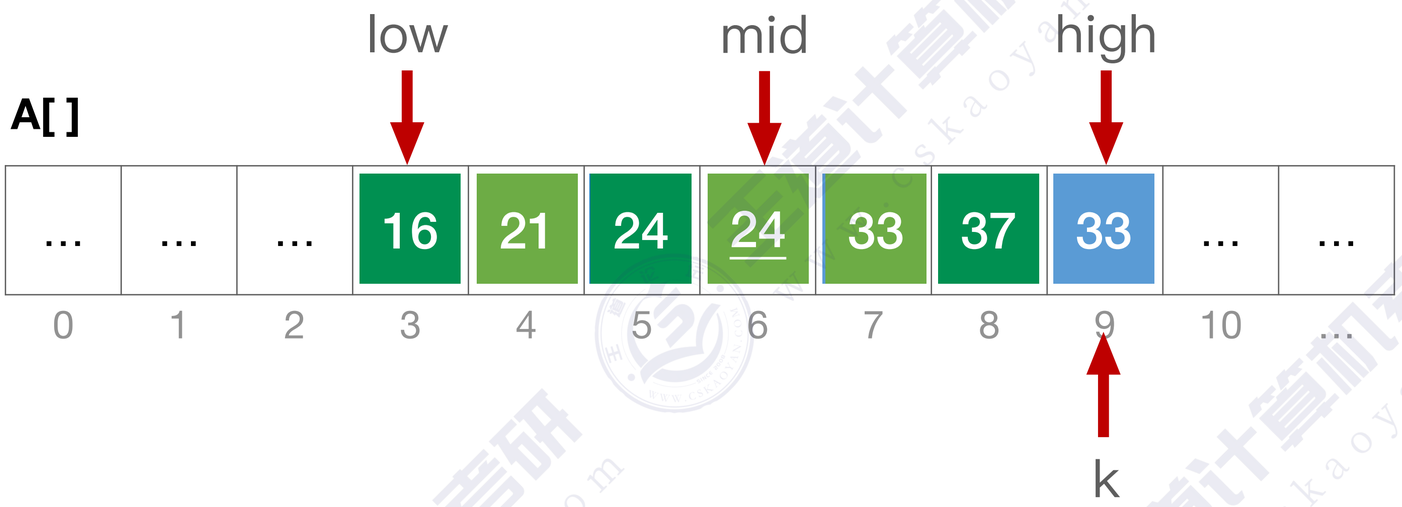
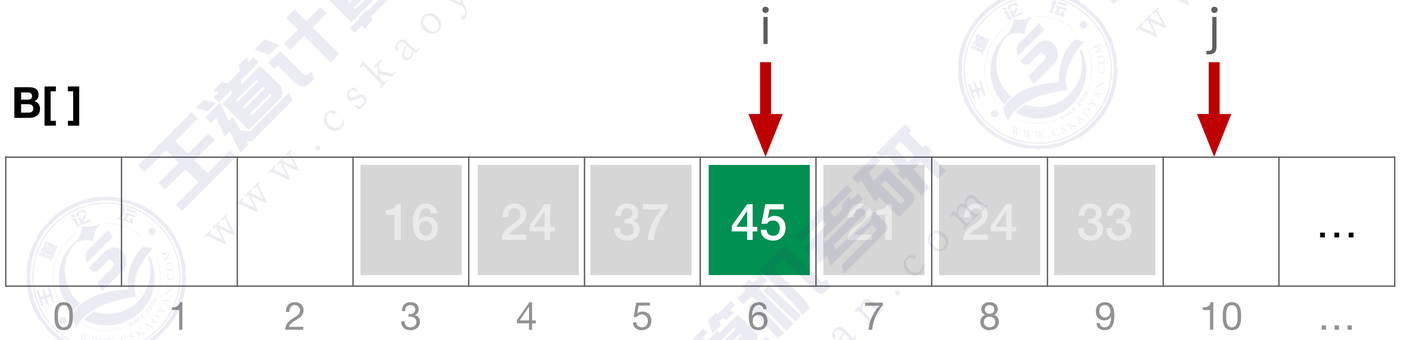
代码实现



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//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
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        B[k]=A[k];                  //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

没有归并完的部分复制到尾部

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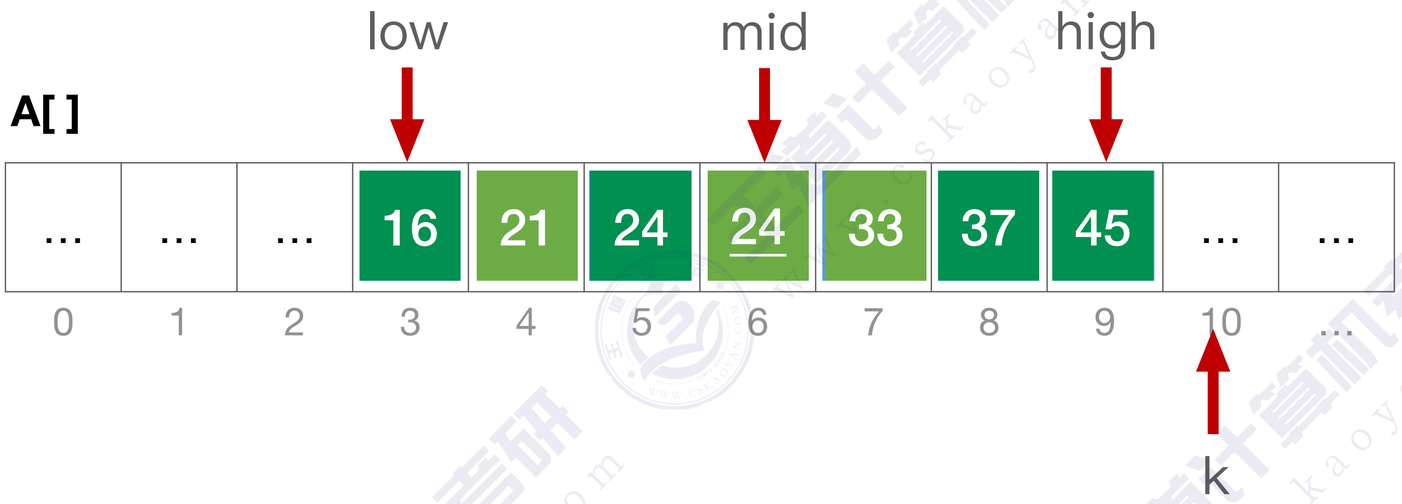
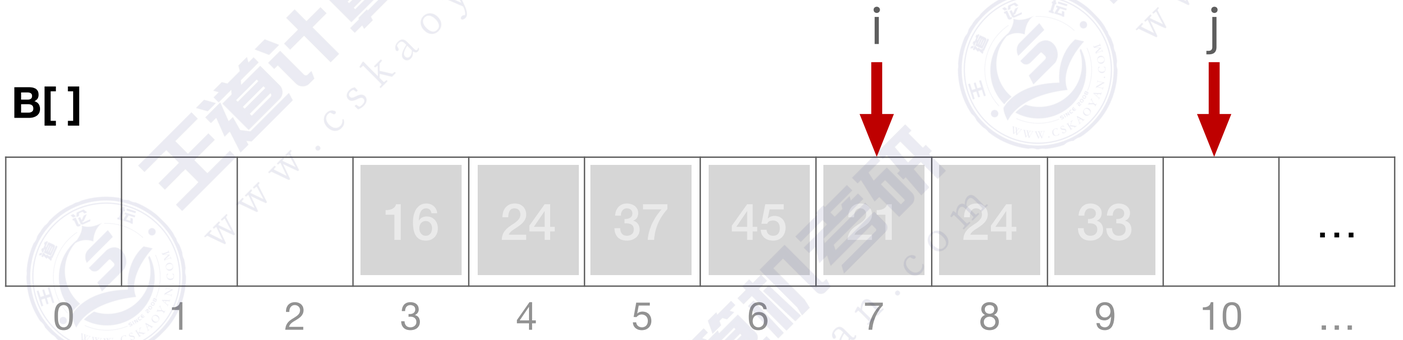
代码实现






```
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    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

没有归并完的部分复制到尾部

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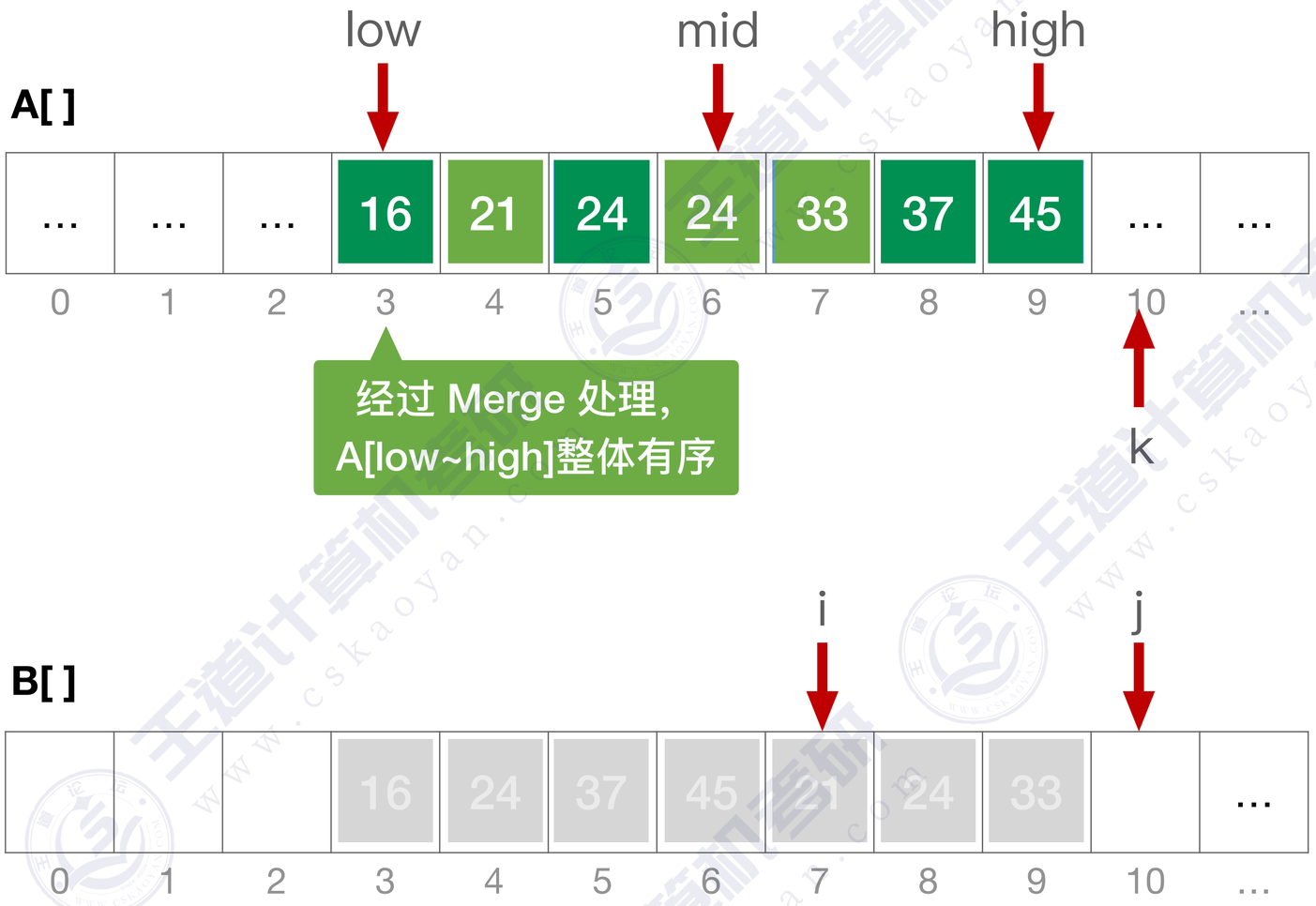
代码实现




```
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//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
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        B[k]=A[k];                  //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}
```

归并

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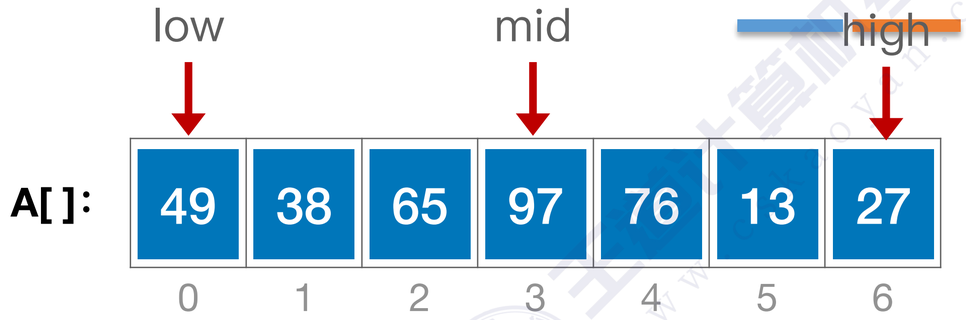
代码实现




```
int *B=(int *)malloc(n*sizeof(int)); //辅助数组B

//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
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    int i,j,k;
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    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

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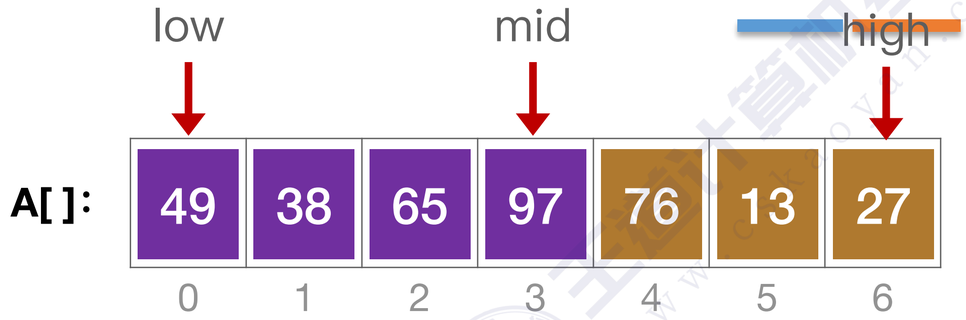
代码实现




```
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    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

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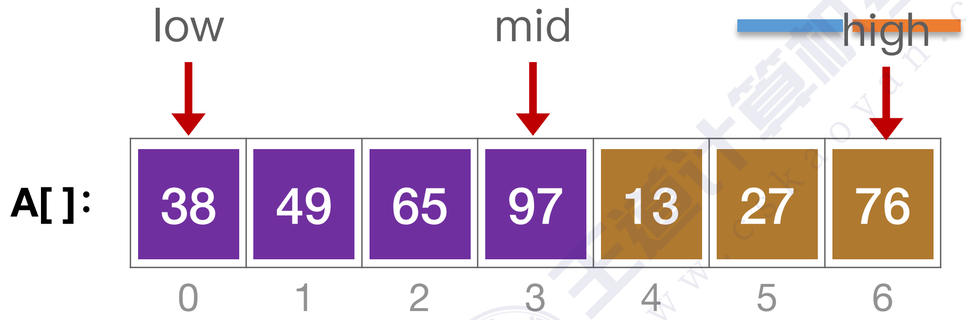
代码实现




```
int *B=(int *)malloc(n*sizeof(int)); //辅助数组B

//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];              //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

将左右两个子序列分别进行归并排序

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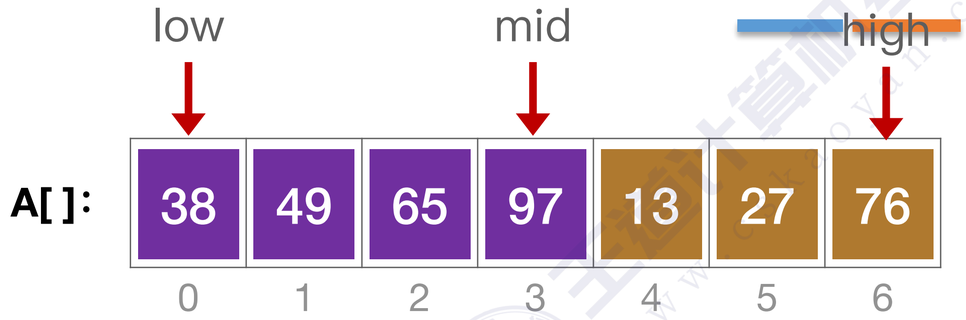


```
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//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];              //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];        //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

左右两个子序列分别有序之后再将二者归并

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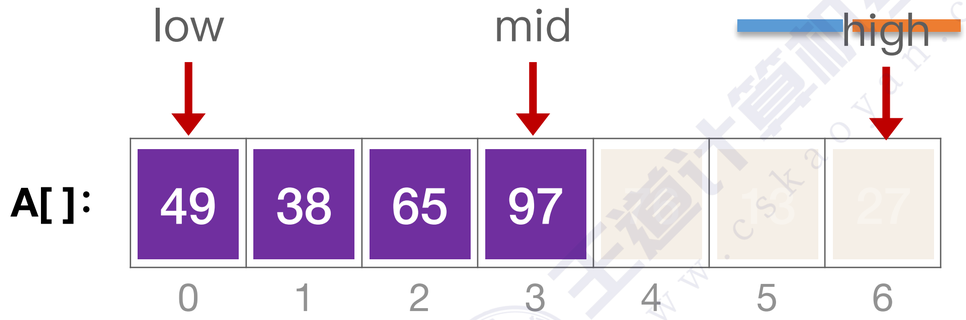


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//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];           //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

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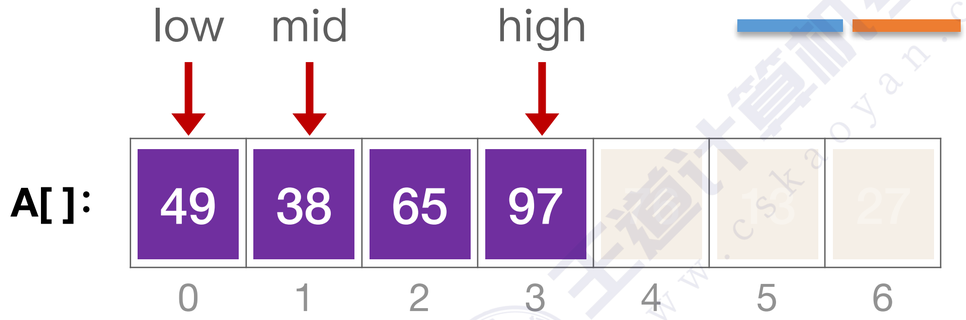
代码实现

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    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

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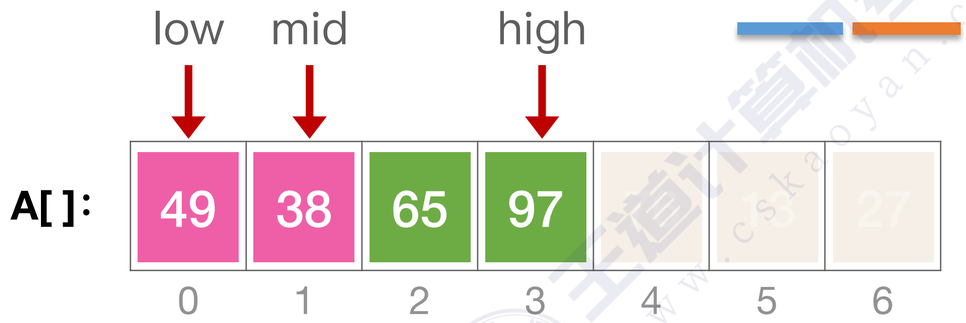
代码实现

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        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

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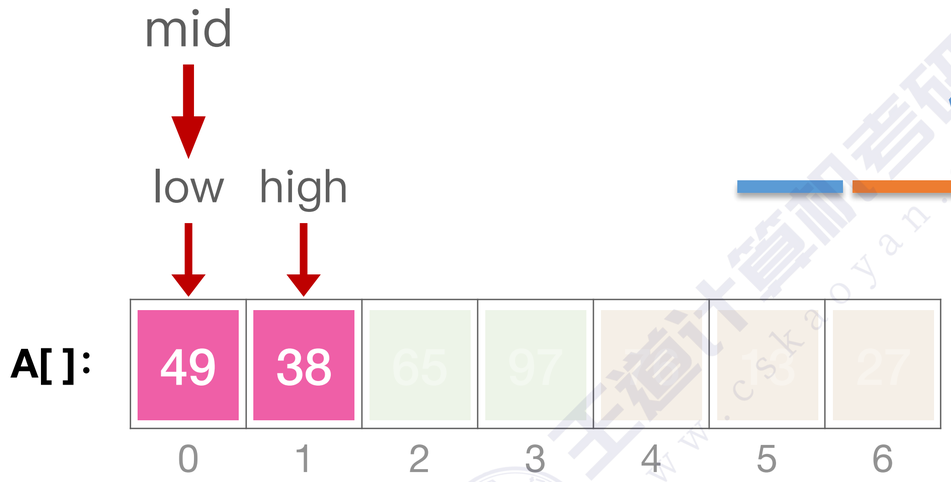
代码实现

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            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
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}

void MergeSort(int A[],int low,int high){
    if(low<high){
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        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
        Merge(A,low,mid,high);   //归并
    }//if
}
```

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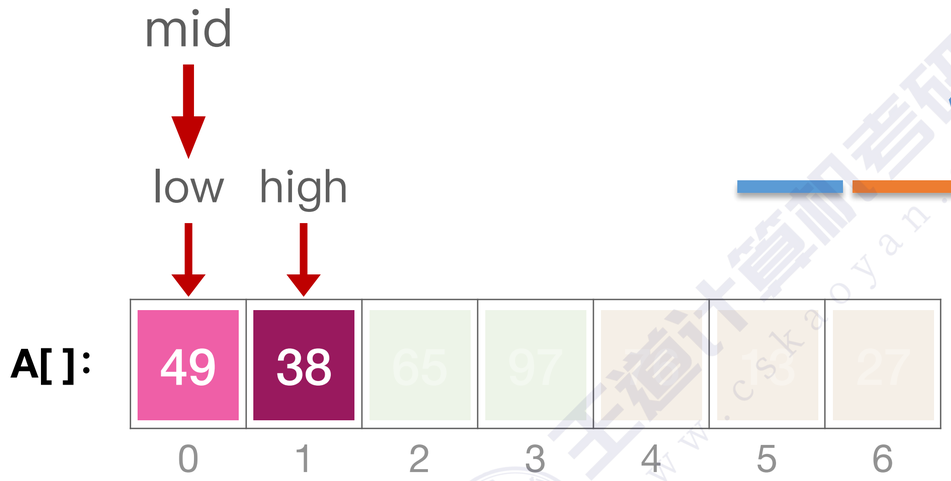
代码实现



将左右两个子序列分别进行归并排序（每个子序列只含有1个元素）

```
int *B=(int *)malloc(n*sizeof(int)); //辅助数组B

//A[low…mid]和A[mid+1…high]各自有序，将两个部分归并
void Merge(int A[],int low,int mid,int high){
    int i,j,k;
    for(k=low;k<=high;k++)
        B[k]=A[k];           //将A中所有元素复制到B中
    for(i=low,j=mid+1,k=i;i<=mid&&j<=high;k++){
        if(B[i]<=B[j])
            A[k]=B[i++];     //将较小值复制到A中
        else
            A[k]=B[j++];
    }//for
    while(i<=mid)   A[k++]=B[i++];
    while(j<=high)  A[k++]=B[j++];
}

void MergeSort(int A[],int low,int high){
    if(low<high){
        int mid=(low+high)/2;    //从中间划分
        MergeSort(A,low,mid);    //对左半部分归并排序
        MergeSort(A,mid+1,high);//对右半部分归并排序
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```

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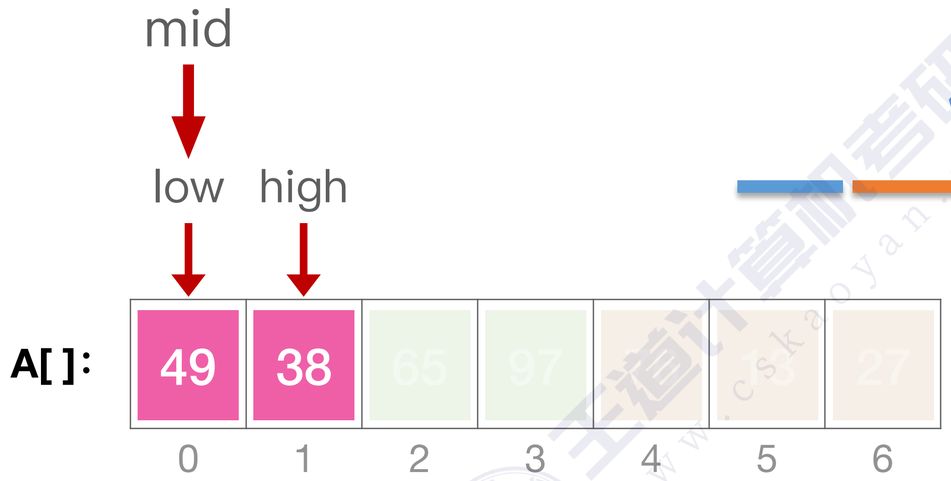
代码实现

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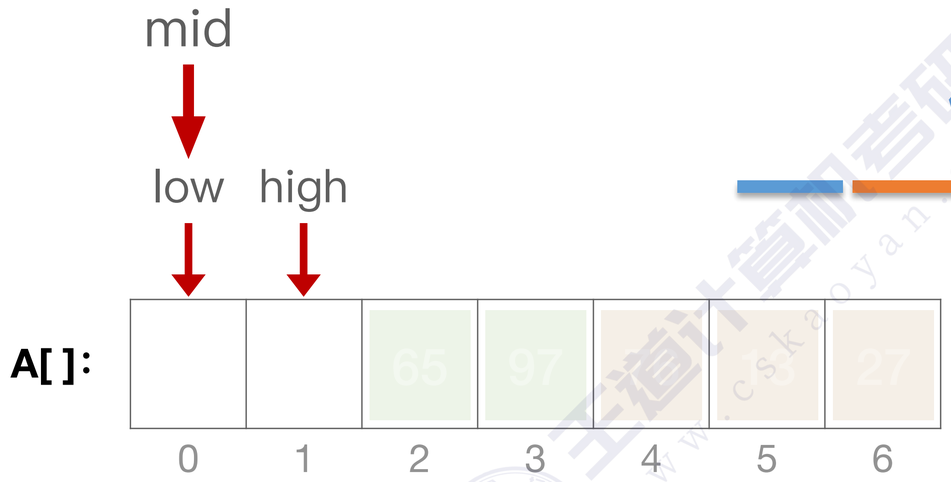
代码实现

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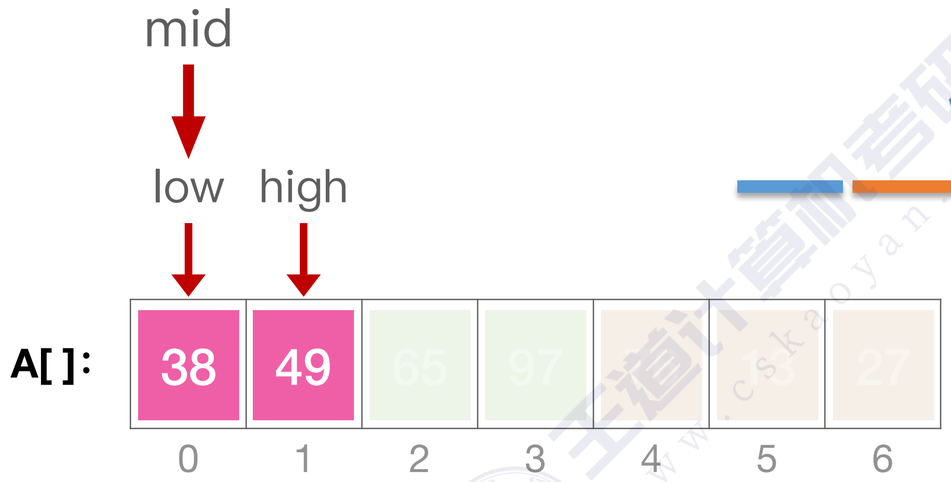
代码实现

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        Merge(A,low,mid,high);   //归并
    }//if
}
```

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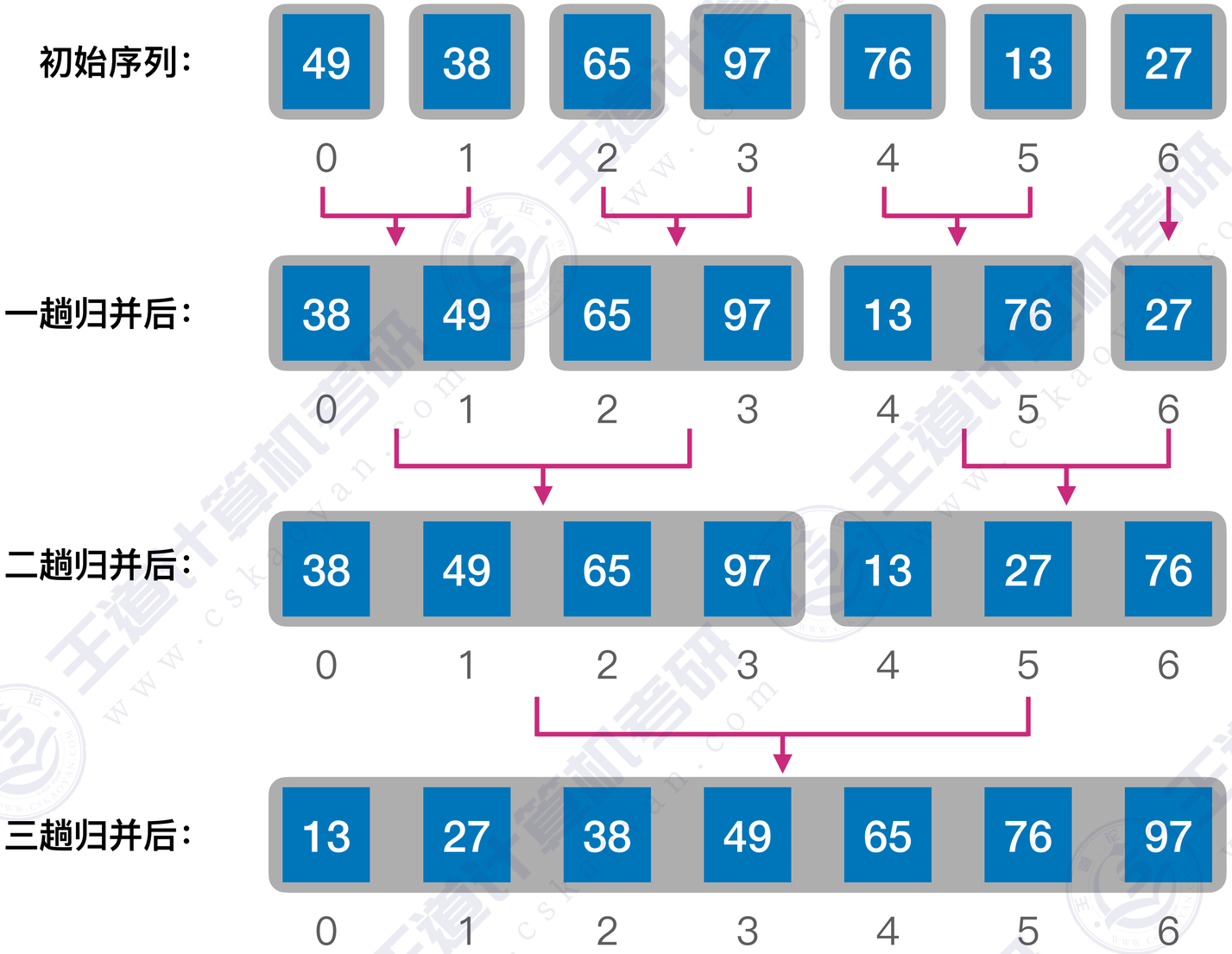
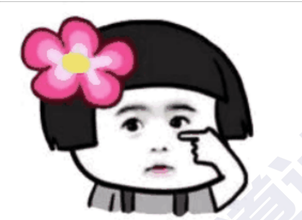
算法效率分析



2路归并的“归并树”——形态上就是一棵倒立的二叉树



看左边

二叉树的第h层最多有 2^{h-1} 个结点

若树高为h，则应满足 $n \leq 2^{h-1}$

即 $h-1=\lceil log_2 n \rceil$

结论：n个元素进行2路归并排序，归并趟数=$\lceil log_2 n \rceil$

每趟归并时间复杂度为 $O(n)$，则算法时间复杂度为 $O(nlog_2 n)$

空间复杂度=$O(n)$，来自于辅助数组B

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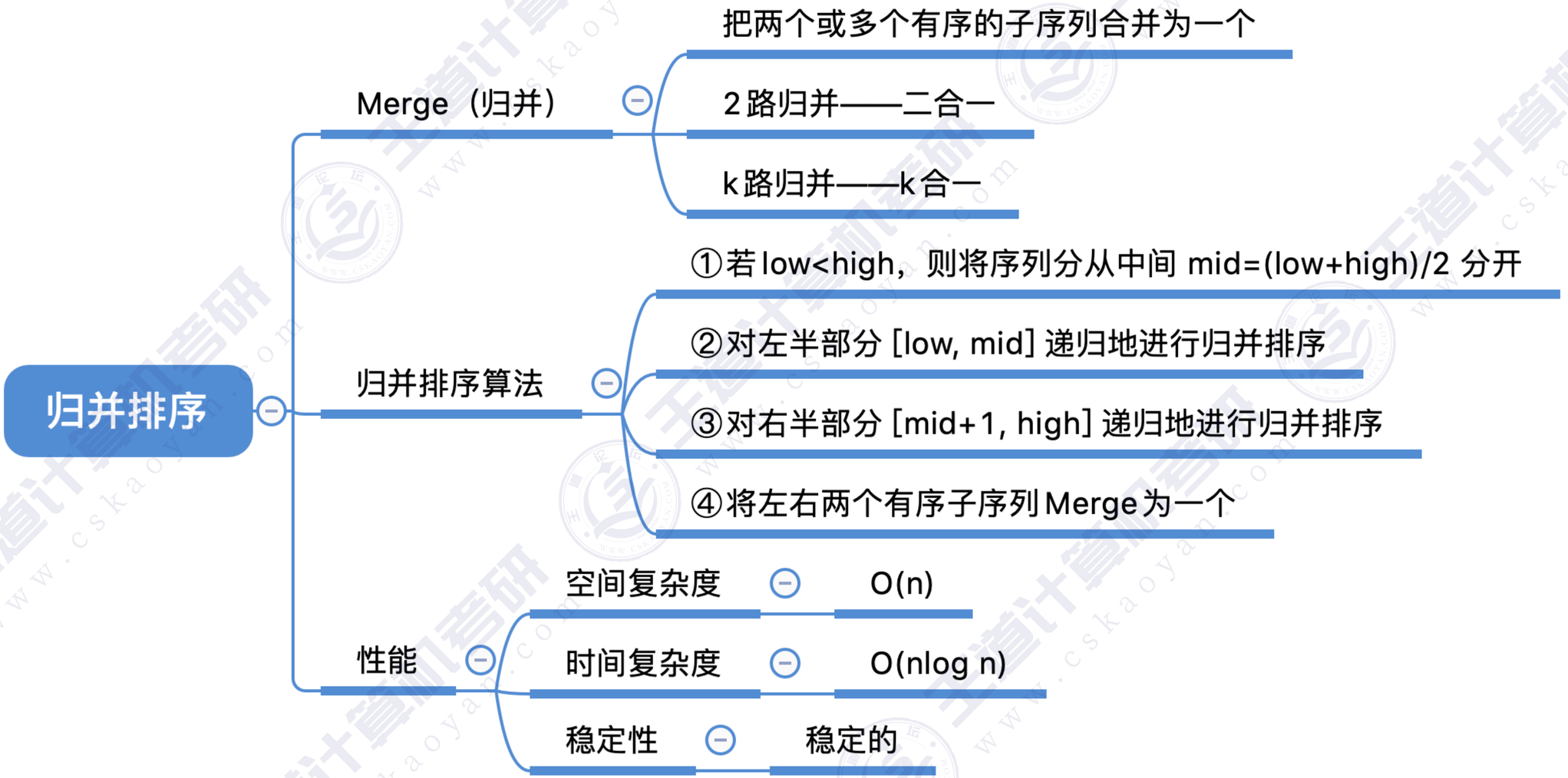
知识回顾与重要考点



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